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**Name of Author:** Danah L. Duke

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# WILDLIFE USE OF CORRIDORS IN THE CENTRAL CANADIAN ROCKIES: MULTIVARIATE USE OF HABITAT CHARACTERISTICS AND TRENDS IN CORRIDOR USE

by

Danah L. Duke ©

A thesis submitted to the Faculty of Graduate Studies and research in partial fulfillment of the requirements for the degree of Master of Science

in

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**Faculty of Graduate Studies and Research**

The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies for acceptance, a thesis entitled **Wildlife Use of Corridors in the Central Canadian Rockies: multivariate use of habitat characteristics and trends in corridor use** submitted by Danah L. Duke in partial fulfillment of the requirements for the degree of Master of Science in Environmental Biology and Ecology.

## Dedication

This thesis is dedicated in loving memory of my mother. Your encouragement got me started, your love and support continues to be felt, every day.

**Abstract**

Wildlife corridors are recognized as important features allowing the persistence of large mammals in human-dominated environments. Using snow-tracked wolf and cougar travel routes within corridors (collected from 1993-2000 in Banff National Park and Yoho National Park), I compared available habitat characteristics to those of wolf and cougar travel routes to determine the characteristics most important for wolves and cougars as they utilize corridors. Slope, distance to cover, relative prey abundance, distance to trails and corridor width were important predictors of both wolf and cougar travel routes. I found that wolves prefer flat to gentle slopes, areas <50m from trails, high relative prey abundance, and in close proximity to forest cover (<25m), the latter being particularly important in corridors adjacent to high levels of human activity. Cover was a particularly important characteristic for cougars, preferring areas <10m from cover, moderate slopes, areas <50m from trails, and moderate prey abundance.

Using track transects, I examined trends in large mammal use of corridors over 8 winters and found that track transects are an effective method to monitor movement trends for deer, sheep, coyote, cougar and wolf. Corridor use decreased over time for sheep, deer and coyote, while cougar and wolf use increased. These results will assist wildlife managers to maintain, restore, and design wildlife corridors to enhance connectivity for wildlife in the Rocky Mountains.

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TABLE OF CONTENTS

## LIST OF TABLES

## TABLE OF FIGURES

# CHAPTER 1

# GENERAL INTRODUCTION

## INTRODUCTION

Human disturbances cause fragmentation of natural habitats resulting in smaller and more isolated wildlife populations. Fragmented populations are subjected to deleterious effects such as insularization, reduced population viability, increased edge effects and loss of genetic variability (Wilcox and Murphy 1985, Hobbs 1993, Ims et al. 1993, Mc Nally and Bennett 1996, Oehler and Litvaitis 1996, Burkey 1997). Over time, these processes may result in the loss of biological diversity and eventually, local extinctions (Wilcox and Murphy 1985, Swart and Lawes 1996). The effects of habitat fragmentation are particularly evident in areas that are heavily influenced by human activity, where habitat persists only in patches within heterogeneous landscapes.

To maintain connections between sub-populations, animals need to be able to move freely between habitat patches. However, movement between patches becomes compromised as different land uses (such as highways and residential areas) limit the use of potential travel routes (Paquet et al. 1996).

Wildlife corridors can provide connectivity within human-dominated landscapes (O'Donnel 1991, Saunders and deRebeir 1991, Beier 1995, Dunning et al. 1995, Odette and Thomas 1996), and reduce the adverse effects of habitat fragmentation (Newmark 1993, Walker and Craighead 1997). Corridors may facilitate the movements of breeding adults, dispersing juveniles, surplus individuals seeking territories, and wandering individuals during daily movements and seasonal migrations (Soule and Gilpin 1991), thus resulting in a higher rate of genetic exchange between individuals from different

subpopulations. A wildlife corridor is defined as a linear two-dimensional landscape element that connects two or more patches of habitat that were historically connected (Soule and Gilpin 1991). Corridors are often referred to as remnant pieces of habitat that provide movement opportunities. Previous research on grizzly bears (*Ursus arctos horribilis*) made the distinction that corridors are areas that provide movement between habitat patches and linkage zones are areas between habitat patches that are suitable for low levels of occupancy in addition to movements (Servheen and Sandstrom 1993). In mountainous environments, where suitable habitat for most wildlife species is limited, corridors and linkage zones are synonymous, as corridors also provide habitat fragments suitable for daily requirements such as food and shelter.

Habitat characteristics that may be important for species as they use corridors include width, length, vegetation cover, habitat quality, topography, human influences, noise, light, edge effects, degree of connectivity and the presence of barriers (Soule and Gilpin 1991, Harrison 1992, Lindenmayer and Nix 1993, Newmark 1993, Fleury and Brown 1997, Rosenberg et al. 1997). Individual animals are more likely to select movement pathways that include important components of their preferred habitat (Rosenberg et al. 1997).

Corridors function at scales ranging from large regional corridors that link entire watersheds, to small local corridors that link patches of residual habitat. Few areas remain in the world today that contain adequate tracts of natural lands to ensure connectivity at the regional scale (Heuer 1995). The Rocky Mountain region represents one of the last areas with the potential for such large-scale connectivity. This large-scale corridor comprises a network of smaller corridors. Examples of small-scale corridors

include remaining pieces of land surrounding residential areas, agricultural areas, ski resorts, hiking trails, golf courses and transportation routes. Maintenance of these small-scale corridors determines the success of regional corridors. If wildlife find it too difficult to use the smaller corridors, the regional corridor becomes jeopardized. Small-scale corridors become increasingly important as habitat fragmentation increases with human activity. Persistence of wildlife populations depends on small-scale corridors to maintain regional connectivity. This paper focuses on small-scale corridors linking patches of habitat around human disturbed areas.

Wide-ranging species, particularly carnivores such as wolves and cougars, have large home ranges that often require navigation through fragmented landscapes. To accomplish life requirements such as hunting, dispersal and reproduction, these species are forced to negotiate human activity and infrastructure (Mladenoff et al. 1995). There is a need to understand movement requirements through human dominated landscapes as fragmentation of ecosystems continues (McLellan and Hovey 2001). There is much information regarding wolf and cougar habitat requirements at regional scales (see Logan and Irwin 1985, Belden et al. 1988, Paquet 1993, Maehr and Cox 1995, Mladenoff et al. 1995, Singleton 1995, Paquet et al. 1996, Boyd 1997, Mladenoff et al. 1997, Massolo and Meriggi 1998). However, little information exists that outlines wolf and cougar habitat requirements for finer scale movements through corridors.

Increasing fragmentation in the Bow Valley of Banff National Park has reduced the amount of habitat available for wildlife. This loss of physical habitat has compromised the connectivity of the landscape and reduced the ability of some animals to complete their daily requirements (Green et al. 1996, Paquet et al. 1996, Heuer et al.

1998, Duke 2000). Concern over habitat fragmentation prompted a survey of animal movements around key areas of residential and commercial development, fenced highway interchanges, golf courses, ski areas and recreational areas - to assess whether large mammals are still able to move around these obstructions (Heuer 1995). Since 1993, winter tracking of wolves and cougars has resulted in the identification of important corridors that facilitate movement. In order to maintain and enhance movements through corridors, it is necessary to know which combination of habitat characteristics is most important to these animals. Recognizing the importance of corridors, the BNP Management Plan (1997) identified "the restoration and maintenance of secure, essential movement corridors in the park " as a strategic management goal. Recent management actions have improved wildlife security in corridors through corridor restorations and human use restrictions. Monitoring of corridors to determine species occurrence and frequency of use is important as it identifies trends in local-scale movement patterns and population-levels. These trends give insight into the functionality of corridors, the impact of management actions and population fluctuations.

## PURPOSE AND OBJECTIVES

The primary focus of this thesis was to examine wildlife use of corridors around developed areas in the Canadian Rockies with a focus on the Bow Valley of Banff National Park (BNP). My first objective was to examine the habitat characteristics important for wolves and cougars as they travel through wildlife corridors at two spatial scales. My second objective was to examine trends in wildlife movements through

corridors in the Bow Valley and determine if track transects are an effective method to monitor trends of wildlife movements through corridors.

In Chapter 2, "Selection of winter habitat by wolves and cougars in corridors of the Central Canadian Rocky Mountains," I investigate the winter travel routes of wolves and cougars as they move around developed areas. I use these data to determine which combination of habitat characteristics is most important for wolves and cougars as they travel through corridors. The habitat characteristics of interest include both natural and anthropogenic factors including slope, distance to cover, relative prey abundance, corridor width, distance to trails and distance to human disturbance. I attempt to investigate the use of habitat characteristics at a regional and individual scale. The specific objectives of this chapter were to:

1) Determine if wolves and cougars prefer certain classes of habitat characteristics within corridors.
2) Determine which combination of habitat characteristics is most important for wolves and cougars as they travel through corridors.
3) Determine if the use of habitat characteristics is consistent across individual corridors.
4) Determine if the multivariate use of habitat characteristics changes across spatial scales.
5) Examine the differences between wolf and cougar use of habitat characteristics.
6) Determine the effect of different types of human disturbances including, roads and high human use (residential/commercial and industrial areas) on wolf and cougar travel routes.

In Chapter 3, "Trends in Wildlife Use of Corridors of Banff National Park: the Use of Track Transects to Monitor Multiple Species", I investigate crossing indices of elk, deer, sheep, coyote, cougar and wolves from transects located in corridors. I use these data to determine both local-scale movement trends and population-level trends in corridor use over an 8-year study period. This method of corridor monitoring is inexpensive and unobtrusive to animals. However, it is unknown if it is an effective method to determine trends in corridor use. My objectives of this chapter were to:

1) For each species, determine if track transects are an effective method to monitor trends in corridor use.
2) For each species, determine which corridors resulted in significant local-scale movement trends.
3) Determine which species showed population-level trends.

Finally, I make conclusions regarding the habitat characteristics important for wolves and cougars as they use corridors in developed areas. I summarize the movement trends of wildlife through corridors and make recommendations regarding the efficacy of track transects to monitor trends. I make management recommendations for the monitoring and management of corridors. It is my hope that the research findings of this project will be used by managers of BNP, and elsewhere, to maintain, design, monitor and restore corridors to enhance connectivity for wildlife in the Rocky Mountains.

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# CHAPTER 2

# SELECTION OF WINTER HABITAT BY WOLVES AND COUGARS IN CORRIDORS OF THE CENTRAL CANADIAN ROCKY MOUNTAINS

## INTRODUCTION

The Bow Valley of Banff National Park (BNP) has been identified as a critical component of the Central Rockies Ecosystem (Green et al. 1996). This regional movement corridor is part of an integrated connection of the Rocky Mountain Cordillera of Canada and the Northern United States for carnivore species such as wolves and cougars. The Rocky Mountain region from Yellowstone to Jasper currently retains a high diversity of carnivore species and offers one of the best opportunities for carnivore conservation on the continent (Carroll et al. 2000). There has been concern that increasing fragmentation in the Bow Valley has reduced the amount of habitat available for wildlife and compromised the connectivity of the landscape, making it difficult for animals to move freely through the valley and the regional landscape (Paquet et al. 1996).

The lower Bow Valley is composed primarily of montane habitat, which is rare in the Rocky Mountain ecosystem (Holland and Coen 1983), yet highly valued for its ability to support a high diversity of wildlife species (Holroyd and Van Tigem 1983). This montane habitat becomes increasingly important during the winter months when wildlife are restricted to the low elevation valley bottoms due to deep snow at higher elevations.

Human disturbance throughout the lower Bow Valley has severed this regional corridor into several small-scale corridors (Paquet et al. 1996). Permanent facilities occupy more than 37% ($53km^2$) of the montane in the Bow Valley (Paquet et al. 1996). This fragmentation has resulted in the loss of physical habitat and connectivity,

ultimately reducing the ability of cougars and wolves to move through the regional corridor (Heuer 1995, Paquet et al. 1996, Stevens and Owchar 1996, Heuer et al. 1998, Duke 1999a, Duke 1999b, Duke 2000). Understanding the habitat characteristics important for movement through small-scale corridors of the Bow Valley and adjoining valleys is essential to maintain and restore regional connectivity of wolves and cougars in the Rocky Mountains. However, little is known about the habitat requirements for wolves and cougars at fine scales, such as corridors, surrounding areas of human disturbance.

Previous research has been conducted on wolf habitat use in flat, homogenous terrain in areas such as Minnesota, Wisconsin and Michigan (Mladenoff et al. 1995, 1997). In less topographically complex environments, animals have access to multiple travel routes linking blocks of habitat. In such areas, the destruction of one corridor is not usually critical as animals can use alternative routes. In the Rocky Mountains however, animals depend on the valley bottoms, which offer the only routes between habitat patches. Under these circumstances animals are forced to travel through human disturbed areas or to avoid areas altogether.

Previous research on wolves in mountainous environments has focused on habitat characteristics in relation to ungulate predation in Glacier National Park (Kunkel 1997) and habitat characteristics of wolf den sites (Matteson 1992). Singleton (1995), Boyd (1997), Paquet (1993), and Paquet et al. (1996) have analyzed regional-scale winter habitat selection of wolves in the Rocky Mountains. These studies have found habitat characteristics important for wolves at regional scales include elevation, aspect, slope, and human disturbance.

Previous mountain lion research has focused on population dynamics, reproductive strategies and prey dynamics (Hornocker 1970, Hemker et al. 1984, Logan et al. 1986, Ross and Jalkotzy 1992). Regional habitat use patterns have been extensively researched in Florida (Belden et al. 1988, Maehr 1990 and Maehr and Cox 1995) and other areas (Logan and Irwin 1985, Koehler and Hornocker 1991, Williams et al. 1995, Jalkotzy et al. 1999). However, little information exists regarding cougar habitat use of small-scale corridors.

In the mountains where snow cover is relatively constant from November until April, snow-tracking is a useful method to document travel routes of animals. Snow-tracking allows continuous trajectories of travel routes to be examined and the habitat use assessed. Traditional methods of determining habitat use (radio-telemetry and point observations) only allow point locations to be documented (Logan and Irwin 1985, Belden et al. 1988, Pereira and Itami 1991, Maehr and Cox 1995, Mladenoff et al. 1995, 1997). Continuous trajectories permit greater understanding of habitat selection and habitat characteristics of travel routes. Without continuous trajectories, analysis of habitat use is confined to a piece-meal approach, extrapolating use from point locations. Snow-tracking is an unobtrusive method that allows detailed information to be collected regarding movement, behaviour and avoidance of human structures and other disturbances.

To assess wildlife needs, habitat that is used by animals can be compared with the habitat that is available, permitting researchers to infer selection or preference (Garshelis 2000). Managers can then manipulate landscapes to contain preferred habitats to enhance use by target species. However, comparing wildlife use of habitat to available habitat can

be misleading as conclusions from these studies depend on the investigators definitions of what constitutes availability (Johnson 1980). Patterns of habitat selection are dependent on the scale of comparison and the distribution of available habitat (Johnson 1980, Manly et al. 1993, Garshelis 2000, Apps et al. 2001). Johnson (1980) defined a hierarchical order of habitat selection. First order selection is defined as the selection of physical or geographic range of a species. Second order selection determines the composition of home ranges of individuals and third order selection pertains to the usage of various habitat components within the home range. It is important to include this hierarchical nature of habitat selection when investigating species-habitat relationships (Johnson 1980, Aebischer et al. 1993, Manly et al. 1993). However, there are few examples of multi-scale analyses of habitat selection by wide-ranging species such as wolves and cougars (Apps et al. 2001).

Traditional methods of determining habitat use often include null hypothesis testing. Criticisms concerning the utility of null hypothesis testing have increased in recent years (Burnham and Anderson 1998, Johnson 1999, Anderson et al. 2000). Traditional null hypothesis testing uses an arbitrary fixed $\alpha$-level that classifies results into biologically meaningless categories of significant and non-significant (Anderson et al. 2000). This approach is relatively uninformative as null hypotheses are almost invariably known to be false before data are collected (Johnson 1999). This chapter adopts an information-theoretic approach to modelling wolf and cougar use of corridors. This method offers alternatives to traditional model selection methods that only allow consideration of single models (Burnham and Anderson 1998, Johnson 1999, Anderson et al. 2000). An information-theoretic approach allows the simultaneous comparison of

multiple models, allowing the investigator to test multiple hypotheses. This approach is useful when examining complex systems and when models other than the null are of interest (Burnham and Anderson 1998).

## Objectives

My overall objective was to determine how habitat attributes and various human influences affect winter habitat selection of wolves and cougars within corridors. Habitat characteristics included natural factors such as slope, distance to cover, corridor width and relative prey abundance. Anthropogenic factors included distance to trails and distance to human disturbance. My specific objectives included the following:

1) Determine if wolves and cougars select certain classes of habitat characteristics within corridors.
2) Determine which habitat characteristics are most important for wolves and cougars as they travel through corridors.
3) Determine if the use of habitat characteristics is consistent across individual corridors.
4) Determine if the multivariate use of habitat characteristics changes across spatial scales.
5) Examine the differences between wolf and cougar use of habitat characteristics.
6) Determine the effect of different types of human disturbance including roads and high human use (residential/commercial and industrial areas) on wolf and cougar travel routes.

To meet my objectives I snow tracked wolf and cougar movements through corridors over eight winters. These travel routes were entered into a GIS (Geographic

Information System) where habitat characteristics were extracted for both travel routes and available habitat. GIS layers were constructed to represent each habitat characteristic. Compositional analysis and selection ratios were used to examine the univariate relationships between wolf and cougar travel routes and habitat characteristics at the regional scale. Multivariate analysis of habitat characteristics was conducted using multiple logistic regression. Two scales of analysis were used to develop multivariate models of wolf and cougar use of corridors. These are arbitrarily defined scales of use that I considered important to understand wolf and cougar use of corridors. These scales included a regional scale (included all corridors), and an individual scale (included each of 11 individual corridors). The regional-scale corresponds to Johnson's (1980) third order selection and the individual scale corresponds to a finer-scale fourth order.

I constructed an apriori set of candidate models (see Appendix 2) using the outlined habitat characteristics to determine which attributes are important for wolves and cougars as they travel through corridors. An information-theoretic approach was used to determine model selection using Akaike Information Criteria (Burnham and Anderson 1998). The best candidate model for each corridor was used to explore the factors affecting wolf and cougar habitat use of corridors. Top models of the regional and individual scales were compared to determine if habitat use of corridors changes across spatial scales. Implications of this research may aid in the maintenance, protection and design of wildlife corridors to enhance connectivity within fragmented mountain environments.

# METHODS

## Study Area

The study area is comprised of corridors located in Banff and YoHo National Parks in the Rocky Mountains of Alberta and British Columbia, Canada. Banff National Park (BNP), 6641km$^2$, is located along the eastern slope of the Continental Range of the southern Canadian Rocky Mountains, about 110 km west of the city of Calgary, Alberta. YoHo National Park (YNP), 1310 km$^2$, is located on the western slope of the continental divide of the Canadian Rocky Mountains. Both BNP and YNP are characterized by extreme mountainous topography. Regionally, the Bow Valley and the Kicking Horse Valley act as a conduit for wildlife movements originating in many other major valleys. Within these regional corridors are numerous fine-scale individual corridors that link areas around human development.

The Bow Valley is used by more than 5 million visitors per year (Green et al. 1996). Three townsites (Field, Lake Louise and Banff), the national railway (Canadian Pacific Highway) and highway (Trans Canada Highway) system, numerous secondary roads and human developments (subdivisions, a golf course, ski areas and recreation grounds) have fragmented the Bow Valley and Kicking Horse Valley. This fragmentation has resulted in numerous small-scale corridors linking areas around human development. This project focuses on ten corridors in the Bow Valley and one corridor in the Kicking Horse Valley. The corridors of the Bow Valley include the Cascade, Sulphur, Golf Course, Indian Grounds, Penstock, Vermillion, Healy North, Healy South, Sunshine, Castle and Lake Louise corridors. The Field corridor is located in the Kicking Horse Valley (Figure 2-1). Corridors in size ranged from 2km$^2$ to 26km$^2$.

Habitat within BNP and KNP is montane, subalpine, or alpine depending on elevation. Low elevation montane is the most productive and biologically diverse habitat found within BNP and YNP, yet only accounts for 3% of the area (Holroyd and Van Tighem 1983). Approximately 82% of BNP's montane habitat is within the Bow River Valley (Holroyd and Van Tighem 1983). Climate ranges from long, cold winters, with infrequent warm periods caused by Chinook winds, to short relatively dry summers. Large mammal associations include moose (*Alces alces*), elk (*Cervus elaphus*), white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), bighorn sheep (*Ovis canadensis*), mountain goat (*Oreamnos americanus*), mountain caribou (*Rangifer tarandus*) wolf (*Canis lupus*), coyote (*Canis latrans*), cougar (*Puma concolor*), grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), and lynx (*Felis lynx*).

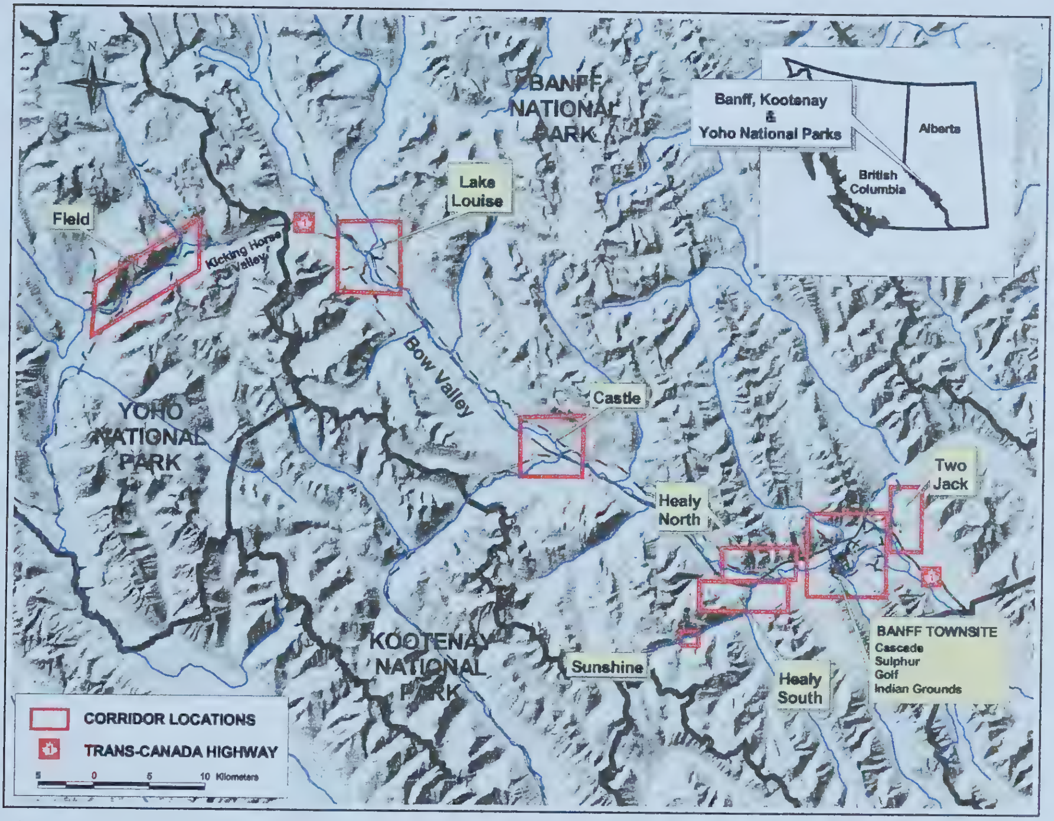



Figure 2-1. Map showing the study area and the general locations of all corridors.

**Data Collection**

Winter snow tracking was used to document travel routes of wolves and cougars through corridors. Winter was defined as the period between November 01 and April 15 of each year. Wolf and cougar tracks were found while monitoring transects located in each corridor. Transects were oriented to bisect the most likely directions of wildlife movements through corridors and, where possible, were located at the most constricted portion of each corridor. Transects extended the entire width of each corridor. Transects were monitored a minimum of 24-72 hours after each snowfall. Animal tracks were regularly forward and backtracked but sufficient distance was maintained to ensure the animals were not disturbed. Each continuous line of tracking is referred to as a 'tracking sequence'. Sequences were followed until they extended to the boundaries of the corridor or until tracks were lost due to poor snow conditions.

Each tracking sequence was recorded onto aerial photographs (1:50,000 ortho-corrected), enlarged to 1:10,000. Garmin GPS units were also used to record UTM locations along each tracking sequence (error <30m). However, for most tracking sessions, Garmin units were not needed due to the ease of landmark identification from the aerial photographs. In areas with few landmarks (i.e. dense forest), mapping errors up to 100m are possible.

**GIS Data Entry**

All tracking sequences were manually digitized into a GIS database (MapInfo Professional 5.0) by species and by year for each corridor. All tracking sequences less than 1500m were excluded from the analysis. All digitized sequences were imported into

a raster GIS (IDRESI, Eastman 1997) at a 5m resolution by year. This resolution minimized the overlapping of travel routes across years. The tracking databases were then converted to a 30m resolution to overlay with habitat variables, excluding distance to cover, which was a five-meter resolution. Tracking sequences remained at a 5m resolution to overlay with distance to cover. Each 30m pixel (5m pixel for distance to cover) represented one tracking point. Tracking sequences from the Field corridor were represented by point locations instead of continuous tracking sequences. These point locations were collected with Garmin GPS units (error <30m) and downloaded into a GIS database. All data were converted into NAD 1983 map datum and UTM zone 11 map projection.

**Available corridor habitat**

Corridors were defined as remnant pieces of land surrounding human development that provided for movement across or through a valley around both natural and artificial barriers. Natural barriers included cliffs and steep avalanche slopes. Artificial barriers included fencing along highways, residential and commercial developments. Corridor widths ranged from 170m to 5000m. Width was restricted by topography (<40° slopes), human development, or a 2500m distance cutoff from valley bottom. Areas >2500m from the valley bottom were considered to lie outside of the zone of influence of human disturbance. All areas >2000m in elevation were excluded from the analysis. This was the maximum elevation used by both cougar and wolf across all study areas. Areas above these elevations tended to be steep rugged peaks with heavy snow cover and were not considered to be available habitat for wolves and cougars.

Corridor length was determined by the extent of the human disturbance within the corridor. Generally, corridors extended a minimum distance to an adjoining valley or a maximum distance of 2500m from human development. Regions outside of the designated corridors were excluded from analysis even if tracking routes were documented within these areas.

All unavailable areas within corridors were masked to accurately represent the available habitat to wolves and cougars. Unavailable areas included fenced areas and buildings. Several corridors were subject to structural changes over the course of the study period (1993-2000). Structural changes included the removal/addition of facilities and fences. Available corridors and tracking sequences were partitioned by year according to structural changes within corridors. Available habitat was represented by the generation of random points within each corridor.

Table 2-1. Corridor descriptions including length, width and area for all individual corridors

| Corridor | Length (m) | Minimum Width (m) | Maximum Width (m) | Area ($km^2$) |
|---|---|---|---|---|
| Cascade | 8130 | 430 | 2438 | 11.53 |
| Indian Grounds | 9650 | 170 | 2312 | 13.04 |
| Golf Course | 5040 | 630 | 2330 | 8.21 |
| Sulphur | 3800 | 830 | 4770 | 6.42 |
| Two Jack | 2500 | 3900 | 4810 | 9.56 |
| Healy North | 5000 | 860 | 1646 | 6.17 |
| Healy South | 4600 | 1325 | 3970 | 6.09 |
| Sunshine | 1800 | 1065 | 1897 | 1.98 |
| Castle | 5400 | 1600 | 4421 | 24.55 |
| Lake Louise | 6800 | 5000 | 5000 | 25.86 |
| Field | 8800 | 820 | 3634 | 22.56 |

**Habitat characteristics**

GIS map layers were constructed to represent habitat characteristics that may influence wolf and cougar travel routes through corridors. Habitat characteristics included the following: slope, distance to cover, distance to trails, distance to human disturbance, corridor width, and relative prey abundance. The rationale for these variables is provided below.

Slope was included as a measure of topography and ease of travel. Vegetation cover (both overstory and understory vegetation) is important as a measure of security for wildlife (Purves et al. 1992). Snow cover during winter months buries a large proportion of understory vegetation (Hovey and Harestad 1992), therefore, distance to overstory vegetation was used as a measure of cover. In areas surrounding human development, hiding cover may be important for wary carnivores, such as cougars, that are known to depend on vegetation for stalking cover (Hornocker 1970, Logan and Irwin 1985, Koehler and Hornocker 1991).

Distance to trails, and human disturbance were included as they are considered indicators of human impacts. Trail layers were comprised of all trails within each corridor. Human disturbance layers were comprised of all residential, industrial and commercial areas, roads (maintained, paved and unpaved), trails (high use trails only, >500 events per month) and the Canadian Pacific Railway (CPR).

Width of corridors was included due to the fact that in mountainous environments, corridors are restricted in width by topography and human developments. Animal movements may be influenced by the confining nature of these corridors.

Prey density was estimated as a measure of relative prey abundance, due to its importance to carnivores as a food source. Low relative prey abundance corresponds to 0-2 pellet groups (all ungulates combined) per $100m^2$. Moderate relative prey abundance corresponds to 2-10 pellet groups per $100m^2$ and high relative prey abundance corresponds to >10 pellet groups per $100m^2$. A detailed description of each habitat characteristic and the origin of digital information can be found in Appendix 1.

Other habitat characteristics, including elevation, aspect, terrain ruggedness, vegetation and snow depth have been considered relevant to wolf or cougar habitat use (Maehr and Cox 1995, Singleton 1995, Paquet et al. 1996, Boyd 1997, Jalkotzy et al. 1999). Elevation and terrain ruggedness were excluded due their high correlation to slope (r= .690, r=.980 respectively, see Table 2-5). I considered slope to have a greater impact than elevation and terrain ruggedness on animal movements at the fine-scale relevant to this study. Aspect was not included due to the lack of variation of aspect within each corridor. While snow depth has been used in regional-scale studies, variation in snow depth across corridors was minimal due to the small size of each corridor. An index of vegetation was not included, as vegetation attributes have been shown not to be strongly correlated with wolf distribution except as they relate to prey density (Carroll et al. 2000).

For all univariate analyses, habitat characteristics were reclassed according to the classes outlined in Table 2-2. For all multivariate analysis, habitat characteristics remained as continuous variables except for relative prey abundance, which was a categorical variable.

Table 2-2. Landscape habitat characteristics and classes used in the analysis of wolf and cougar travel routes.

| CHARACTERISTIC | CODE | CLASS | CHARACTERISTIC | CODE | CLASS |
|---|---|---|---|---|---|
| Slope (S) | 1 | 0° | Distance to Trails (T) | 1 | 0-50m |
| | 2 | 1-5° | | 2 | 50-100m |
| | 3 | 5-10° | | 3 | 100-250m |
| | 4 | 10-20° | | 4 | 250-500m |
| | 5 | 20-30° | | 5 | >500m |
| | 6 | >30° | Distance to Human Disturbance (HD) | 1 | 0-50m |
| Distance to Cover (DC) | 1 | 0-10m | | 2 | 50-100m |
| | 2 | 10-25m | | 3 | 100-250m |
| | 3 | 25-50m | | 4 | 250-500m |
| | 4 | >50m | | 5 | >500m |
| Corridor Width (CW) | 1 | <500m | Relative Prey Abundance (P) | 1 | Low |
| | 2 | 500-750m | | 2 | Moderate |
| | 3 | 750-1000m | | 3 | High |
| | 4 | 1000-2000m | | | |
| | 5 | >2000m | | | |

## Analytical Methods

### Univariate Analyses

Univariate analyses were conducted at the regional scale to determine if wolves and cougars select certain classes of habitat characteristics within corridors. Compositional analysis was used to determine whether wolf and cougar use of habitat

characteristics was random or in proportion to overall availability (Aebischer et al. 1993). Compositional analysis overcomes the violations of assumptions of other statistical techniques (see Aldredge and Ratti 1986, 1992) by using log-ratio transformations of proportional data. This method pairs the log-ratio of used with the log-ratio of available habitat and tests the hypothesis that all habitats are simultaneously used randomly (no preference for any of the potential habitat classes). This method avoids problems with non-independence of habitat class proportions that affect other methods of assessing habitat use and availability (Aebischer et al. 1993).

Previous studies have used compositional analysis to study habitat utilization of individual animals (Aebischer et al. 1993, Tufto et al. 1996, Mladenoff et al. 1999, McLellan and Hovey 2001). I used this technique to analyze habitat utilization within corridors using point data derived from wolf and cougar tracking sequences. Individual corridors were used as the sampling unit. This means that all wolf and cougar tracking sequences for one corridor were compared with the available habitat within that corridor. This method was used instead of the traditional method of individual animals representing the sampling unit. Compositional analysis is well suited to accommodate data of movement trajectories, obtained through snow-tracking, as they provide a precise estimate of proportional habitat use (Aebischer et al. 1993).

Each individual corridor provided an independent measure of corridor habitat use. Tracking sequences ranged in length from 1500m to several kilometres. Instead of weighting each tracking sequence by length, all sequences within a corridor were combined to represent wolf or cougar use of that corridor. Longer sequences contributed

more information than shorter sequences. Proportions of used and available were generated using Idresi. Compositional analysis was conducted using RESELECT.

Multivariate Analyses

Multivariate analysis of habitat characteristics was conducted using multiple logistic regression to identify which combination of habitat characteristics were a better predictor of wolf and cougar travel routes. Two scales of analysis, regional and individual, were used to develop multivariate models of wolf and cougar use of corridors. Resulting models were compared to identify which combinations of habitat characteristics were consistent predictors of wolf and cougar travel routes across spatial scales

For all regional scale models, tracking data from each corridor were standardized, so that sequences from individual corridors contributed equally to the models. The number of tracking points contributing to each individual corridor is outlined in Table 2-3 and Table 2-4. This same number of random points was used for each corridor at each scale of analysis. Total availability of each habitat characteristic was compared with the sample of random points to ensure that the random sample accurately represented total availability.

Pixels within each corridors were used by wolf or cougar tracking sequences more than one time. Tracking sequences were overlaid by year so that multiple uses of pixels could be represented by a frequency value generated by converting the travel routes from a 5m resolution to a 30m resolution and summing the values across years. Each model

was weighted by the frequency of use of each point. Random points were given a frequency value of 1.

Used and available points were overlaid with each habitat characteristic, resulting in habitat characteristics assigned to each used and available point. These resulting databases were exported from Idresi and brought into SPSS 8.0 (SPSS Inc. 1999) for multiple logistic regression analysis.

I developed an apriori set of candidate models (see Appendix 2) from the habitat characteristics outlined in Table 2-2 that explicitly stated different hypothesis of factors influencing wolf and cougar travel routes. Logistic regression models were of the form:

$$Logit(p) = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_i X_i.$$

where p = the probability that the point is used, $\beta_o$ = constant, $\beta i$ = coefficients for habitat characteristics and Xi = the data value for habitat characteristic i.

I used binary logistic regression in SPSS to estimate models for corridors and to estimate parameter coefficients and likelihood values. Akaike Information Criteria (AIC) was calculated from the general formula AIC = -2 (log likelihood) +2K, where K = the number of parameters (Burnham and Anderson 1998). I then used $\Delta$AIC, using a cutoff of $\Delta$AIC$\leq$4 (Burnham and Anderson 1998), to select the best approximating models for each spatial scale. $\Delta$AIC was calculated by ranking the AIC values from lowest to highest and assigning the lowest a zero value. Differences from this were then calculated and $\Delta$AIC <4 represented an approximate 95% confidence set of the best models. I used the sum of Akaike weight ($\omega_l$) to rank the importance of habitat variables. Each spatial scale included the same set of candidate models, except when habitat variables were unavailable (see Appendix 2). The sign of the beta coefficient was used to determine the

effect of each variable on wolf and cougar use of corridors. If a variable was included in the multivariate model then the univariate results were used to determine which habitat class was preferred.

Variables were screened for multicollinearity (see Table 2-5) using Spearman's correlation coefficients (Tabacknick and Fidell 1996). If variables were highly correlated (r>0.70), only the variable with the greatest explanatory ability was included in the models (Tabachnick and Fidell 1996). To determine the effect of different types of human disturbance, I generated models which included the variables distance to roads and distance to human disturbance. Results focus on the models that include human disturbance only (includes roads, residential, commercial and industrial areas) however, I include the results for models which include roads and human disturbance variables together (see Appendix 3) in an attempt to differentiate the effect of these two variables.

The area under a relative operating characteristic curve (ROC) was used to measure the discrimination capacity of each model. This relatively unbiased method eliminates the need to determine an arbitrary choice of a threshold probability used in other validation techniques (Turner 1978, Pearce and Ferrier 2000). ROC curves provide a graph of relative proportions of correctly and incorrectly classified predictions over a continuous range of threshold probabilities (Tabacknick and Fidell 1996, Pearce and Ferrier 2000). Once a ROC curve is determined, the area under the curve is calculated to give an index, which describes the discrimination capacity of the model. ROC indices range from 0.5 for models with no discrimination capacity to 1 for models with perfect discrimination. ROC values ranging from 0.5 to 0.7 indicate poor discrimination capacity. Values between 0.7 and 0.9 indicate a reasonable discrimination ability and

values higher than 0.9 indicate very good discrimination (Pearce and Ferrier 2000). ROC values are reported in Tables 2-6 and 2-7.

## RESULTS

Wolf travel routes were monitored in ten different corridors over a seven year period (winters 1993-2000). Cougar travel routes were monitored in eight different corridors over a seven year period (winters 1993-2000). Travel routes totaling 1,431km of wolf tracking and 629km of cougar tracking were entered into the GIS database (Tables 2-3 and 2-4). The average length of wolf travel routes was 5.23km and the average length of cougar travel routes was 4.4km. All travel routes were >1500m. The number of tracking routes per corridor for wolves ranged from 8 to 63. The number of tracking routes per corridor for cougars ranged from 6 to 30. The number of wolf tracking points per corridor ranged from 452 to 5695. The number of cougar tracking points per corridor ranged from 502 to 3286.

Table 2-3. Tracking Summary of Wolf Travel Routes, Winters 1993-2000

| Corridor (Years Monitored) | Number of Routes | Total Distance (km) | Mean Distance (km) | Number of Points |
|---|---|---|---|---|
| Cascade 1993-2000 | 63 | 341 | 5.98 | 5695 |
| Indian 1993-2000 | 26 | 207 | 7.97 | 3021 |
| Golf 1993-2000 | 8 | 57 | 7.1 | 1239 |
| Sulphur 1993-2000 | 14 | 64 | 4.6 | 1775 |
| Two Jack 1993-2000 | 59 | 304 | 5.16 | 5595 |
| Healy North 1993-2000 | 40 | 127 | 3.18 | 1474 |
| Healy South 1993-2000 | 10 | 61 | 6.12 | 1109 |
| Castle 1993-1997 | 34 | 134 | 3.9 | 3857 |
| Lake Louise 93-97, 99-00 | 11 | 65 | 5.94 | 1275 |
| Field 1998-2000 | 30 | 71 | 2.36 | 452 |
| TOTAL | 295 | 1431 | --- | 25092 |
| AVERAGE | 26.8 | 130.1 | 5.23 | 2282 |

Table 2-4. Tracking Summary of Cougar Travel Routes, Winters 1993-2000

| Corridor (Years Monitored) | Number of Routes | Total Distance (km) | Mean Distance (km) | Number of Points |
|---|---|---|---|---|
| Cascade 1993-2000 | 30 | 124 | 4.2 | 3286 |
| Indian 1993-2000 | 22 | 116 | 5.27 | 2606 |
| Golf 1993-2000 | 20 | 119 | 5.96 | 2418 |
| Sulphur 1993-2000 | 14 | 97 | 6.9 | 1876 |
| Two Jack 1993-2000 | 9 | 27 | 2.95 | 730 |
| Healy North1993-2000 | 22 | 66 | 2.98 | 1297 |
| Healy South 1993-2000 | 16 | 62 | 3.9 | 1372 |
| Sunshine 1993-2000 | 6 | 18 | 2.9 | 502 |
| TOTAL | 139 | 629 | --- | 14087 |
| AVERAGE | 17.4 | 78.6 | 4.4 | 1760 |

Table 2-5. Spearman rank correlation coefficients of slope (S), elevation (E), terrain ruggedness (TR), distance to cover (DC), distance to trails (T), distance to roads (R), distance to human disturbance (HD), low relative prey abundance (LP), moderate relative prey abundance (MP), high relative prey abundance (HP), and corridor width (CW). N= 3450, which comprises a random 15% of the available database.

| | S | E | TR | DC | T | R | HD | LP | MP | HP | CW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S | 1.0 | .690 | .980 | -.137 | .161 | .315 | .280 | -.300 | .272 | .223 | -.195 |
| E | | 1.0 | .604 | -.177 | .417 | .363 | .342 | -.191 | .103 | .206 | .237 |
| TR | | | 1.0 | -.130 | .158 | .312 | .275 | -.246 | .204 | .268 | -.205 |
| DC | | | | 1.0 | -.129 | -.191 | -.193 | .202 | -.185 | -.233 | -.177 |
| T | | | | | 1.0 | .140 | .229 | -.255 | .343 | .312 | .291 |
| R | | | | | | 1.0 | .822 | -.355 | .437 | .109 | -199 |
| HD | | | | | | | 1.0 | -.278 | .397 | .032 | .092 |
| LP | | | | | | | | 1.0 | -.606 | -.482 | .093 |
| MP | | | | | | | | | 1.0 | .176 | -.059 |
| HP | | | | | | | | | | 1.0 | .374 |
| CW | | | | | | | | | | | 1.0 |

## Univariate Results

Habitat Characteristics of Wolf Travel Routes through Corridors

Wolf travel routes were not randomly used (P<0.10) for the following habitat characteristics: slope, distance to cover, distance to trails and distance to human disturbance. Wolf travel routes were located randomly (P>0.10) for corridor width, and relative prey abundance. Selection ratios, representing the log-transformed ratios of used

to available were used to indicate preference and avoidance of habitat characteristic classes.

Slope classes for wolf travel routes differed significantly from random (p=0.009). As slope increased, wolf use decreased. Wolves used flat/gentle slopes more than their availability and avoided use of steep slopes (Figure 2-2).

Distance to cover differed significantly between wolf travel routes and available corridor habitat (p=0.005). As the distance to cover increased, wolf use decreased. Wolves showed a weak preference for areas <25m from cover and a weak avoidance of areas >25m from cover (Figure 2-2).

Wolf travel routes were not located randomly within corridors in regard to distance to trails (p=0.004). Wolves used areas < 500m from trails more than their availability and avoided areas > 500m from trails. Wolves showed a particularly strong preference for areas <50m from trails (Figure 2-2).

Wolf travel routes were not located randomly within corridors in regard to distance to human disturbance (p=0.091). Wolves used areas between 50m and 500m from human disturbance more than their availability and avoided areas <50m and >500m from human disturbance (Figure 2-2).

Wolf travel routes did not differ significantly from random with respect to relative prey abundance (p=0.221). Wolves showed a weak avoidance for areas of low relative prey abundance and used areas with moderate and high relative prey abundance more than their availability (Figure 2-2).

Wolf travel routes did not differ significantly from random with respect to corridor width (p=.501). Wolf use of corridor width was variable across corridor width classes (Figure 2-2).

Habitat characteristics of Cougar Travel Routes through Corridors

Cougar travel routes were not randomly used ($P<0.10$) for the following habitat characteristics: slope, distance to cover, and distance to human disturbance. Cougar travel routes were located randomly ($P>0.10$) for corridor width, distance to trails, and relative prey abundance.

Cougar travel routes were not located randomly within corridors in regards to slope (p=0.002). Cougars used moderate (1-5°-20-30°) slopes more than their availability and used flat and very steep slopes less than their availability (Figure 2-2).

Cougar travel routes were not located randomly within corridors in regard to distance to cover (p=0.001). As distance to cover increased, use decreased. Cougars used areas < 10m from cover more than their availability and areas >10m from cover less than their availability.

Cougar travel routes did not differ significantly from random with respect to distance to trails (p=0.123). Cougars used areas < 500m from trails more than their availability and areas > 500m from trails less than their availability. Cougars showed a particularly strong preference for areas <50m from trails (Figure 2-2).

Distance to human disturbance differed significantly between cougar travel routes and available corridor habitat (p=0.077). Cougars used areas between 50m and 500m

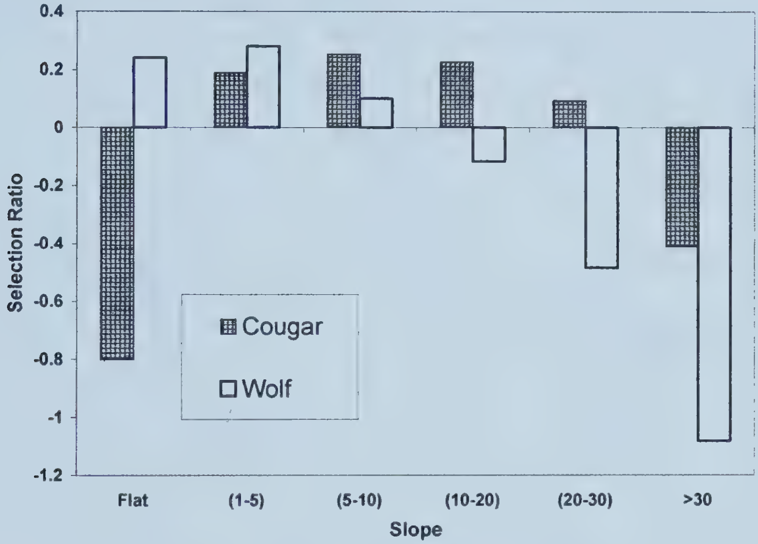
from human disturbance more than their availability and areas <50m and areas >500m less than their availability.

Cougar travel routes did not differ significantly from random with respect to relative prey abundance (p=0.356). Cougars used areas with moderate prey abundance more than their availability and areas of low and high relative prey abundance less than their availability.

Cougar travel routes did not differ significantly from random with respect to corridor width (p= 0.581). Cougars used corridor widths of <1000m more than their availability and corridor widths >1000m less than their availability.

Figure 2-2. Selection ratios of wolf and cougar travel routes for each habitat characteristic class. Selection ratios represent the log transformed ratio of used to available. Values >0 indicate selection (used more than its availability), values<0 indicate avoidance (used less than its availability). Probability of overall random use is indicated. N=10 for wolf travel routes and N=8 for cougar travel routes unless otherwise stated.

**Slope**
Wolf p=0.009, Cougar p=0.002




**Distance to Cover**
Wolf p=0.005, Cougar p=0.001

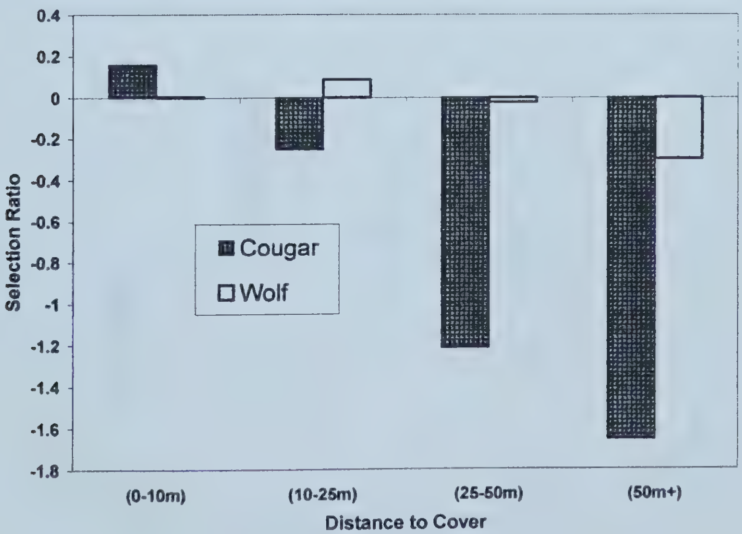
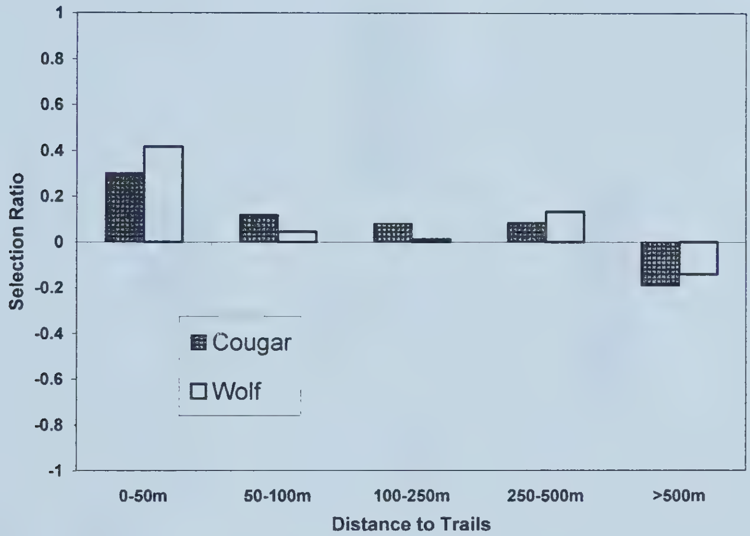


Figure 2-2 cont'd. Selection ratios of wolf and cougar travel routes for each habitat characteristic class. Selection ratios represent the log transformed ratio of used to available. Values >0 indicate selection (used more than its availability), values <0 indicate avoidance (used less than its availability). N=10 for wolf travel routes and N=8 for cougar travel routes unless otherwise stated. Probability of overall random use is indicated.

**Distance to Trails**
Wolf p=0.004, Cougar p=0.122




**Distance to Human Disturbance**
Wolf p=0.091, Cougar p=0.077

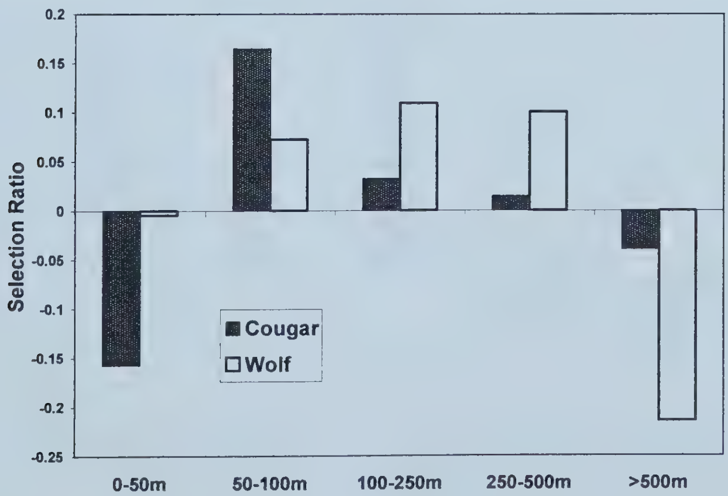
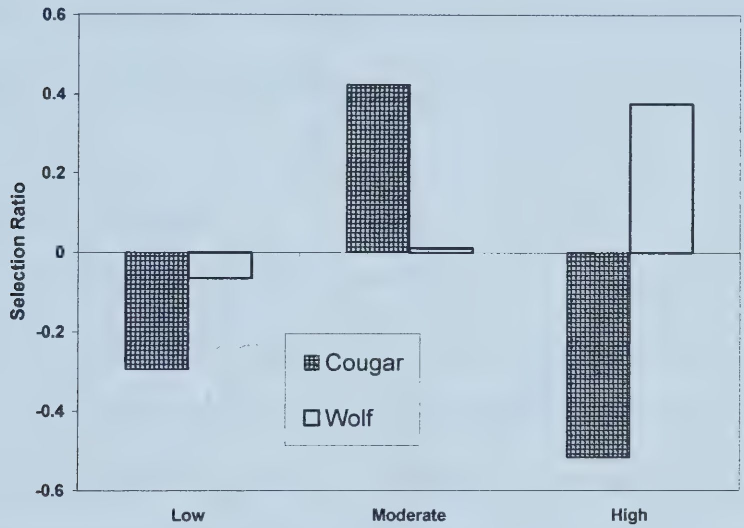


Figure 2-2 cont'd. Selection ratios of wolf and cougar travel routes for each habitat characteristic class. Selection ratios represent the log transformed ratio of used to available. Values >0 indicate selection (used more than its availability), values <0 indicate avoidance (used less than its availability). N=10 for wolf travel routes and N=8 for cougar travel routes unless otherwise stated. Probability of overall random use is indicated.

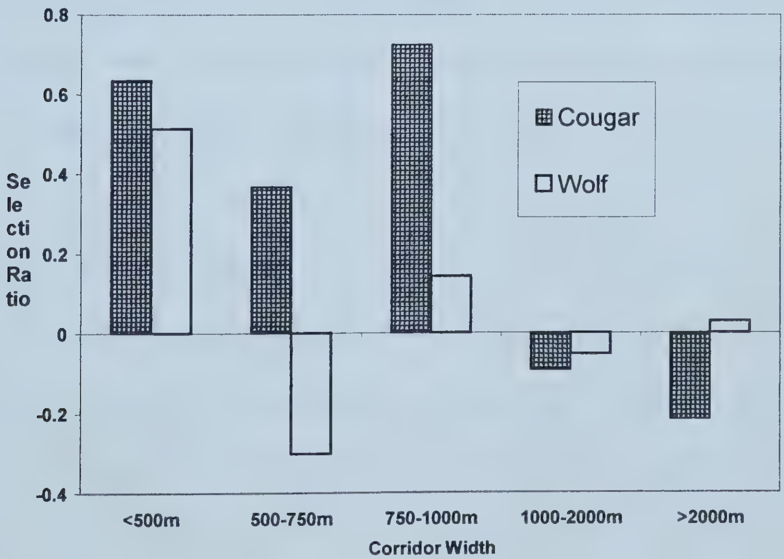
**Relative Prey Abundance**

Wolf p=0.221, N=8, Cougar p=0.356, N=7




**Corridor Width**

Wolf p=0.501, Cougar p=0.581



**Multivariate Results**

This paper focuses on the results of two spatial scales. A third spatial scale, a local scale, representing the use of four corridors surrounding the Banff townsite, was originally included in the analysis. This local scale was an intermediate scale between the regional and individual scale. Results yielded minimal differences between the regional scale models and the local scale models. Therefore, results for the regional and individual scale models only will be presented.

Wolf - Regional Scale

AIC analysis ($\Delta AIC \leq 4$) resulted in one regional-scale wolf corridor model (see Table 2-6). Slope, distance to cover, distance to trails and human disturbance, relative prey abundance and corridor width were included in the top model. Increasing slope resulted in decreased probabilities of wolf travel routes. Increasing distance to cover and increasing distance to trails resulted in decreased probabilities of wolf travel routes for the top model. Increasing distance to human disturbance resulted in decreasing probabilities of wolf travel routes. Compared to low relative prey abundance, moderate and high relative prey abundances increased the probability of wolf travel routes. The ROC value for the top model was 0.658.

Wolf - Individual Scale

Ten different individual corridors were included in the wolf individual scale analysis. It is the differences from the regional scale corridor models that are of interest and not the specific differences between each individual corridor model. Thirty-five top

models resulted from the individual-scale model selection (see Table 2-6). The effect of slope differed from the regional model for three individual corridors. The effect of distance to cover differed from the regional model for one individual corridor. The effect of distance to trails differed from the regional-scale model for two individual-corridors. The effect of distance to human disturbance differed from the regional models for two individual-corridors. The effect of relative prey abundance differed from the regional-scale corridor model in four individual-corridors. The effect of corridor width differed for three individual-corridors. ROC values for individual corridors ranged from .603 to .943.

Cougar - Regional Scale

AIC analysis ($\Delta$AIC$\leq$4) resulted in one regional-scale cougar corridor models (see Table 2-7). Slope, distance to cover, distance to trails and human disturbance, relative prey abundance and corridor width were included in the top model. Increasing slope resulted in increasing probabilities of cougar travel routes. Increasing distance to cover resulted in decreased probabilities of cougar travel routes. Increasing distance to trails and increasing distance to human disturbance resulted in decreased probabilities of cougar travel routes for both top models. Compared to low relative prey abundance, moderate relative prey abundances increased the probability of cougar travel routes for both top models. Compared to low relative prey abundances, high relative prey abundance decreased the probability of cougar travel routes for both top models. Increasing corridor width resulted in decreased probability of cougar travel routes for both top models.

Cougar - Individual Scale

Eight different corridors were included in the cougar individual-scale analysis. Fourteen top models resulted from the individual-scale model selection (see Table 2-7). The effect of slope differed from the regional model for four individual corridors. The effect of distance to cover did not differ from the regional model for all individual corridors. The effect of distance to trails differed from the regional-scale model for five individual-corridors. The effect of distance to human disturbance differed from the regional-scale model for one individual-corridor. The effect of relative prey abundance differed from the regional-scale corridor model in two individual-corridors. The effect of corridor width differed for one individual-corridor. ROC values for individual corridors ranged from 0.640 to .0964.

Summaries of top wolf and cougar regional-scale models with preferred habitat characteristics are provided in Table 2-8.

Table 2-6. Top multiple logistic regression model set comparing wolf travel routes to available habitat within corridors across two spatial scales. Multiple logistic regression models take the form $Logit(p) = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_i X_i$, where p= probability that the point is used, $\beta o$ = constant, $\beta i$ = coefficients for habitat characteristics and Xi = the data value for habitat characteristic i. Habitat characteristics are abbreviated as outlined in Table 2-2. * indicates variables excluded from the model. N/A indicates variables that were consistent across the corridor and not included in the model. Coefficients in bold indicate p>0.05.

| Corridor | Model # | ΔAIC | $\omega_I$ | $\beta_o$ | S | DC | T | HD | MP | HP | CW | ROC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Regional Scale*** | | | | | | | | | | | | |
| | 57 | 0.00 | .956 | 2.84 | -.042 | -.010 | -.0005 | -.0005 | .230 | .322 | .0000 | .658 |
| ***Individual Scale*** | | | | | | | | | | | | |
| Cascade | 39 | 0.00 | .702 | 4.30 | -.057 | * | -.0015 | -.0003 | **.084** | .709 | * | .771 |
| Cascade | 29 | 2.96 | .160 | 4.31 | -.057 | **-.001** | -.0016 | -.0003 | **.075** | .725 | * | .771 |
| Cascade | 41 | 3.73 | .109 | 4.32 | -.057 | * | -.0015 | -.0003 | **.089** | .709 | **.0000** | .771 |
| Golf | 57 | 0.00 | .693 | -.172 | .0069 | -.022 | -.0027 | -.0004 | .260 | -.978 | .0013 | .670 |
| Golf | 42 | 1.63 | .306 | .256 | * | -.022 | -.0025 | -.0002 | -1.23 | -.299 | .0013 | .668 |
| Indian | 26 | 0.00 | .436 | 1.58 | -.048 | -.017 | * | * | .531 | .897 | .0001 | .606 |
| Indian | 3 | 1.31 | .227 | 1.75 | -.043 | -.017 | * | * | .518 | .881 | * | .603 |
| Indian | 27 | 1.94 | .165 | 1.70 | -.048 | -.017 | * | **-.0002** | .459 | .817 | .0001 | .606 |
| Indian | 24 | 3.74 | .067 | 1.84 | -.043 | -.017 | * | **-.0002** | .456 | .811 | * | .604 |
| Indian | 31 | 3.93 | .061 | 1.57 | -.048 | -.017 | **.0000** | * | .526 | .892 | .0001 | .605 |
| Sulphur | 34 | 0.00 | .680 | 4.75 | -.019 | * | * | -.0013 | -.561 | -.992 | -.0012 | .605 |
| Sulphur | 27 | 2.55 | .190 | 4.74 | -.020 | -.005 | * | -.0013 | -.550 | -.758 | -.0011 | .606 |

Table 2-6 cont'd

| Corridor | Model # | ΔAIC | $\omega_I$ | $\beta_o$ | S | DC | T | HD | MP | HP | CW | ROC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Two Jack | 57 | 0.00 | .532 | 10.9 | -.010 | -.003 | -.0007 | -.0007 | .772 | **-.027** | -.0021 | .715 |
| Two Jack | 42 | 1.98 | .197 | 10.6 | * | -.003 | -.0008 | -.0007 | .781 | **.003** | -.0020 | .715 |
| Two Jack | 32 | 2.71 | .137 | 10.4 | * | * | -.0008 | -.0007 | .796 | **.003** | -.0019 | .715 |
| Two Jack | 41 | 2.76 | .134 | 10.7 | -.008 | * | -.0007 | -.0006 | .795 | **-.018** | -.0020 | .715 |
| Healy North | 41 | 0.00 | .364 | -24.6 | **.017** | * | **-.0004** | .0040 | 4.11 | N/A | .0166 | .943 |
| Healy North | 34 | 1.38 | .183 | -25.1 | **.014** | * | * | .0039 | 4.22 | N/A | .0167 | .940 |
| Healy North | 20 | 1.66 | .159 | -24.6 | * | * | * | .0040 | 4.24 | N/A | .0164 | .939 |
| Healy North | 32 | 1.73 | .153 | -24.1 | * | * | **-.0003** | .0041 | 4.15 | N/A | .0163 | .941 |
| Healy North | 57 | 3.54 | .062 | -24.6 | **.017** | **.002** | **-.0004** | .0040 | 4.10 | N/A | .0166 | .941 |
| Healy South | 32 | 0.00 | .708 | .710 | * | * | .0006 | -.0026 | -1.99 | N/A | .0009 | .726 |
| Healy South | 41 | 3.27 | .138 | .888 | **-.005** | * | .0006 | -.0025 | -1.95 | N/A | .0008 | .726 |
| Healy South | 42 | 3.41 | .129 | .669 | * | **-.004** | .0006 | -.0026 | -2.02 | N/A | .0009 | .727 |
| Castle | 41 | 0.00 | .437 | -1.46 | -.027 | * | -.0009 | -.0019 | -.304 | N/A | .0020 | .812 |
| Castle | 38 | 0.18 | .400 | -1.46 | -.027 | * | -.0009 | -.0019 | * | N/A | .0020 | .812 |
| Castle | 30 | 1.99 | .162 | -1.45 | -.028 | **-.010** | -.0009 | -.0019 | * | N/A | .0020 | .812 |
| Castle | 57 | 2.36 | .134 | -1.45 | -.027 | **-.009** | -.0009 | -.0020 | -.288 | N/A | .0020 | .812 |
| Lake Louise | 30 | 0.00 | .499 | 5.48 | -.039 | -.049 | -.0007 | **.0015** | N/A | N/A | -.0006 | .643 |
| Lake Louise | 21 | 2.68 | .131 | 1.87 | -.038 | -.048 | -.0008 | **.0015** | N/A | N/A | * | .641 |
| Field | 5 | 0.00 | .405 | 1.87 | .026 | * | -.0023 | -.0040 | N/A | N/A | * | .811 |
| Field | 21 | 0.58 | .304 | 2.01 | .023 | **-.005** | -.0023 | -.0041 | N/A | N/A | * | .816 |
| Field | 38 | 2.44 | .119 | 1.46 | .029 | * | -.0025 | -.0041 | N/A | N/A | **.0002** | .813 |
| Field | 11 | 3.64 | .066 | 2.15 | * | -.006 | -.0021 | -.0034 | N/A | N/A | * | .815 |
| Field | 30 | 3.65 | .065 | 1.67 | .025 | **-.004** | -.0024 | -.0041 | N/A | N/A | **.0002** | .817 |

Table 2-7. Top multiple logistic regression model set comparing cougar travel routes to available habitat within corridors across two spatial scales. Multiple logistic regression models take the form $Logit(p) = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_i X_1$, where p= probability that the point is used, $\beta o$ = constant, $\beta i$ = coefficients for habitat characteristics and Xi = the data value for habitat characteristic i. Habitat characteristics are abbreviated as outlined in Table 2-2. * indicates variables excluded from the model. N/A indicates variables that were consistent across the corridor and not included in the model. Coefficients in bold indicate p>0.05.

| Corridor | Model # | ΔAIC | $\omega_I$ | $\beta_o$ | S | DC | T | HD | MP | HP | CW | ROC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Regional Scale*** | | | | | | | | | | | | |
| | 57 | 0.00 | .968 | 2.31 | .007 | -.033 | -.0003 | -.0007 | .491 | -.390 | -.0001 | .629 |
| ***Individual Scale*** | | | | | | | | | | | | |
| Cascade | 57 | 0.00 | 1.00 | 4.26 | -.011 | -.015 | -.0021 | -.0008 | .379 | **-.103** | -.0006 | .740 |
| Golf | 57 | 0.00 | 1.00 | 1.52 | -.028 | -.048 | -.0014 | .0005 | 1.14 | .418 | -.0004 | .679 |
| Indian | 29 | 0.00 | .710 | 1.84 | .034 | -.027 | .0004 | -.0008 | .230 | -.363 | * | .658 |
| Indian | 57 | 3.26 | .139 | 1.92 | .035 | -.027 | .0004 | -.0008 | .220 | -.388 | **-.0001** | .658 |
| Indian | 24 | 3.35 | .133 | 1.91 | .032 | -.027 | * | -.0008 | .277 | -.333 | * | .653 |
| Sulphur | 57 | 0.00 | .992 | 3.59 | -.037 | -.083 | .0021 | -.0018 | -.721 | -8.46 | -.0005 | .688 |
| Two Jack | 27 | 0.00 | .869 | 34.3 | .044 | -.031 | * | -.0024 | 1.08 | **-5.14** | -.0086 | .819 |
| Two Jack | 57 | 3.78 | .131 | 33.9 | .046 | -.031 | **.0000** | -.0024 | 1.06 | **-5.12** | -.0086 | .819 |
| Healy North | 57 | 0.00 | 1.00 | -19.3 | .187 | -.043 | -.0012 | -.0026 | 5.27 | N/A | .0127 | .964 |
| Healy South | 42 | 0.00 | .872 | 4.45 | * | -.049 | .0007 | -.0019 | **-7.16** | N/A | -.0013 | .694 |
| Healy South | 31 | 3.84 | .128 | 6.41 | -.032 | -.034 | .0004 | * | **-5.75** | N/A | -.0025 | .640 |
| Sunshine | 11 | 0.00 | .514 | 2.48 | * | -.012 | .0014 | -.0055 | N/A | N/A | * | .675 |
| Sunshine | 21 | 0.78 | .347 | 2.30 | **.0176** | -.013 | .0014 | -.0065 | N/A | N/A | **-.0037** | .675 |

Table 2-8. Summary of habitat characteristics included in top regional-scale models. The beta sign or effect of each habitat characteristic, and all preferred habitat classes are indicated.

| Habitat Characteristic | Wolf | Effect | Cougar | Effect |
|---|---|---|---|---|
| Slope | Flat, Gentle | Negative | Moderate | Positive |
| Distance to Cover | <25m | Negative | <10m | Negative |
| Distance to Trails | <50m | Negative | <50m | Negative |
| Distance to Human Disturbance | <500m | Negative | <500m | Negative |
| Relative Prey Abundance | High | Positive | Moderate | Positive |
| Corridor Width | <500m | Positive | 750-1000m | Negative |

## DISCUSSION

As human development expands in the Rocky Mountains and habitat fragmentation and habitat loss increases, it will become increasingly important for corridors to connect animal sub-populations. With this comes a need to determine which classes of habitat characteristics wolves and cougars prefer, and which combination of habitat characteristics is most important for these species as they travel through corridors.

Wolf and cougar travel routes were influenced by the habitat characteristics of corridors and the importance of habitat characteristics varied across spatial scales. Table 2-8 summarizes which habitat characteristics are important for wolves and cougars as they move through corridors. Tables 2-6 and 2-7 show how the importance of these habitat characteristics changes between the regional and individual scales. I believe it is most important ecologically to focus on the results of the regional-scale models. Individual model results were dependent on the availability of each habitat characteristic within individual corridors and do not reflect the overall use of corridors by wolves and cougars. The first section of the discussion will focus on wolf responses and the second will focus on cougar responses followed by a comparison of the two.

### Corridor Use By Wolves

At the regional scale, slope, distance to cover, distance to trails and human disturbance, relative prey abundance and corridor width were included in the top model, indicating their importance to wolf travel routes. ROC values (0.658) indicated a low to reasonable discrimination ability for the top regional scale model. At the individual-scale, importance of habitat variables varied across corridors. No variable was included in all

individual-scale models. Human disturbance was included in the greatest number of individual models (91%), followed by relative prey abundance (89%), suggesting they were the most important variables.

The effect of various habitat characteristics varied between corridors at the individual scale. The variation in the sign of beta coefficients can be attributed to variation in availability of habitat characteristics in each individual corridor. For example, effect of slope in the Field Corridor was positive, and negative in the Indian Grounds Corridor. Availability of flat slopes for the Field Corridor was 20.41% and 50.99% for steep slopes. The Indian Grounds Corridor was comprised of 72.6% flat slopes and 0.26% steep slopes. The differences in availability make conclusions regarding preference of slope difficult to make. This emphasizes the importance of analyzing use of corridors across all corridors (regional-scale), to determine the overall effect of habitat characteristics across a range of habitat availability.

Wolf responses to habitat characteristics of corridors at the regional scale were similar to those important for determining wolf occupancy at home range scales, supporting the statement that in mountainous environments corridors provide important habitat. These habitat characteristics include low elevation (flat/gentle slopes) (Ream et al. 1985, Paquet 1993, Singleton 1995, Paquet et al. 1996, Boyd 1997), forest cover (Massolo and Meriggi 1998), human influences (Mladenoff et al. 1995, Paquet et al. 1996, Massolo and Meriggi 1998), and prey abundance (Huggard 1993, Paquet et al. 1996, Massolo and Meriggi 1998). I found all of these corridor habitat characteristics to be important for wolves.

Slope was included in the top regional model indicating the importance of slope for wolf travel routes. Wolves preferred flat and gentle slopes (0-10$^{o}$ slopes) and avoided steep slopes, supporting previous wolf research (Ream et al. 1985, Paquet 1993, Singleton 1995, Paquet et al. 1996, Boyd 1997). Preference for gentle slopes or low elevations is particularly pronounced in winter months when deep snow precludes the use of higher elevation habitat (Ream et al. 1985, Paquet et al. 1996). Use of low elevation habitat can also be due to the attraction to high relative prey abundance (Huggard 1993, Weaver 1994).

Distance to cover was included in the top regional model. Increasing distance to cover negatively affected the occurrence of wolf travel routes. Wolves preferred areas 0-25m from cover and avoided areas >25m, from cover. Massolo and Meriggi (1998) also found forest cover to be an important variable explaining wolf presence, probably due to the fact that forest cover provided suitable habitats for prey species and undisturbed habitats for denning, rendezvous sites and shelter. In contrast, Boyd (1997) found cover to have no significant effect on wolf use of habitat. In the Bow Valley, wolves generally select for areas in close proximity to cover, possibly due to the increased security that wolves prefer as they move through corridors highly impacted by human disturbance. The importance of cover as a security measure in heavily disturbed areas, is supported by the individual-scale models. For example, in corridors most heavily influenced by humans, such as the Golf Course corridor and Indian Grounds corridor, distance to cover was an important variable. In less disturbed corridors such as the Castle, Healy South and Healy North corridors, distance to cover was excluded from top models.

Distance to human disturbance and trails were included in the top regional-scale model. Increasing distance to human disturbance and trails had a negative effect on wolf travel routes, meaning wolves used areas closer to trails and human disturbance than random. The response to human disturbance was contrary to other studies (Mladenoff et al. 1995, Singleton 1995, Paquet et al. 1996, Mladenoff et al. 1997, Massolo and Meriggi 1998). A large proportion of all human disturbance was comprised of roads, and for some corridors (e.g. Castle, Healy South), roads constituted all of the human disturbance. Previous studies have documented wolf avoidance of trails and roads (Mladenoff et al. 1995, Singleton 1995, Paquet et al. 1996, Mladenoff et al. 1997). However, most of these studies include areas where wolves are subject to hunting and trapping. Some authors (Mech 1988, Mladenoff 1997) suggest that it is not roads per se that are avoided by wolves but roads indicate human contact and the likelihood of deliberate or accidental human-caused mortality. In Banff and YoHo National Parks, wolves are protected from hunting but are still subject to vehicle and railway caused mortalities. Protection from hunting may result in an increased acceptance and use of roads and trails. Also, wolves use trails and roads in winter months to facilitate travel through deep snow (Paquet et al. 1996, Paquet et al. 2001). Therefore, it is not necessarily the human presence associated with trails and roads that attract wolves, but the ease of travel that they offer.

Previous studies have found evidence that wolves may select or avoid roads based on the amount of human use (Thurber et al. 1994). These studies determine thresholds of road densities for wolf use of roads. Results from Paquet et al. (1996) indicated that the Highway 1A in BNP (250 vehicles per day, BNP unpub. data) was nearly transparent to wolf movements, while the Trans Canada Highway (TCH) (5,100 vehicles per day) was a

serious barrier to wolf movements. This suggests that wolves have differential responses to varying traffic levels. All roads bisecting corridors are considered secondary roads and receive minimal traffic compared to the TCH. Other studies have also shown wolves make greater use of secondary roads (Thurber et al. 1994, Paquet et al. 1996).

Interpretation of the wolf response to human disturbance requires an understanding of why wolves are not utilizing areas greater distances (>500m) from human disturbance. In the mountains, most areas >500m from human disturbance include steep slopes. Humans reside, work and recreate in the flat, montane valley bottom resulting in the valley being inundated with various human disturbances. Wolf preference for flat and gentle slopes results in what appears to be an attraction to human disturbance. However, it is the attraction to flat, gentle slopes that attracts wolves to areas close to human disturbance. In addition, prey species, especially in winter, use low elevation montane habitat for (Woods et al. 1996). Urban elk found around the Banff Townsite use road-side ditches, recreational grounds and residential areas which also attracts wolves to these human disturbed areas.

Limitations of this study prevent us from determining the time of day wolves use corridors (75% time of day unknown, 21% night, 4% day). However, other research in BNP suggests that wolves are most active during the night in areas close to human disturbance (Melanie Percy pers. commun.). This may suggest that wolves use areas around trails and human disturbance during the night when human activity is minimal. This accounts for the perceived attraction to human disturbance. Data used in this study include winter use only of corridors, when human activity in BNP and KNP is lowest

(Pacas 1996). Wolf responses to human disturbance and trails might be different at other times of the year when human activity increases (Thurber et al. 1994).

It has been suggested that wolves use areas within their home ranges in ways that maximize encounters with prey (Huggard 1993). Previous wolf research in the Rocky Mountains has shown that wolf-habitat use is linked to ungulate distribution and abundance (Paquet et al. 1996). My research supported these findings, with moderate and high relative prey abundance increasing the probability of wolf travel routes. This suggests wolves are utilizing corridors to maximize their encounters with prey. Paquet et al. (1996) suggested that if a particular habitat is highly attractive, wolves appear willing to risk increased exposure to humans. Many corridors included in the study area have areas of high relative ungulate abundance that are mainly comprised of habituated elk around the Banff townsite (Woods et al. 1996). These high concentrations of elk around areas of high human disturbance may entice wolves to use areas they may otherwise avoid.

It has been stated that as long as wolves are not unduly persecuted they appear to have an ability to survive in highly altered landscapes and occupy areas with greater human activity than previously assumed (Fritts and Carbyn 1995, Mladenoff et al. 1995, Mladenoff 1997 and all cited references). It is important to note that although wolves are capable of moving through human dominated landscapes, areas with low human contact are important to recovering or colonizing wolf populations (Mladenoff et al. 1995). Therefore, while wolves can adapt to high human disturbance within corridors, they still require secure core areas (Weaver et al. 1996).

Previous multivariate analyses of regional wolf habitat use has shown a combination of variables including elevation, aspect, slope, roads, and prey are important variables for wolf use of habitat. (see Mladenoff 1995, Boyd 1997). My results, which focus on wolf habitat use within human dominated corridors, indicate that there are several habitat characteristics that are important for wolf travel routes, and it is the combination of factors that collectively constitute an effective corridor for wolves. These habitat characteristics include slope, distance to cover, distance to trails, relative prey abundance and corridor width. This study was able to discern that wolves prefer flat to gentle slopes in close proximity to forest cover (<25m), the latter being especially important in corridors adjacent to high levels of human use. Although wolves are known to be sensitive to human disturbance, they used areas in close proximity to humans (<500m), utilizing areas of moderate and high prey abundance.

**Corridor Use by Cougars**

At the regional scale, all variables including slope, distance to cover, distance to trails and human disturbance, relative prey abundance and corridor width were included in the top regional model indicating their importance to cougar travel routes. ROC values (0.629) indicated a low discrimination ability for the top cougar regional-scale model.

At the individual scale, importance of habitat variables varied slightly across corridors. Distance to cover and relative prey abundance were included in all individual-scale models suggesting these were the most important variables. Human disturbance was excluded from one individual model while slope and distance to trails was excluded from two individual models each. Corridor width was excluded from three individual models.

Similar to wolf responses, the effect of habitat characteristics varied across individual corridors. This was due to the differences in availability within each individual corridor. However, the effect of distance to cover remained constant across all individual corridors.

Cougar use of habitat characteristics in corridors was similar to cougar use of habitat characteristics of cougars at broader scales. It has been reported that cougars prefer steep, rugged terrain, habitats that provide adequate forest cover, and increased likelihood of encounters with prey (Hornocker 1970, Beldan et al. 1988, Laing 1988, Logan and Irwin 1985, Maehr and Cox 1995, Williams et al. 1995, Murphy 1998). I found that all of these habitat characteristics were important for cougars as they used corridors.

Slope was included in the top regional model, indicating the importance of slope for cougar travel routes. Cougars preferred moderate slopes (5-10$^{o}$ and 10-20$^{o}$) and avoided flat and very steep (>30$^{o}$) slopes. Steep slopes allow cougars to approach prey from above and allow increased speed of attack (Jalkotzy et al. 1999). Most cougar attacks occurred on downhill slopes (Ross and Jalkotzy unpubl. data).

Corridor width was an important variable explaining cougar travel routes. Increasing corridor width had a negative effect on cougar travel routes. Cougars showed a weak preference for corridor widths ranging from 750-1000m. Previous research examining cougar use of corridors reported panthers using bands of remnant forest as narrow as 100m (Maehr 1990). However, the use of these areas may be confounded by the attraction for slope, distance to cover and moderate and high prey abundances. Interpretation of this variable is difficult, as in order to travel through a corridor animals have to use the narrowest regions of the corridor. It would be more useful to compare

frequency of use between areas of varying width to determine preference of corridor widths.

Distance to cover was included in the top regional model. As distance to cover increased, cougar use decreased. Stalking cover has been found to be an important habitat characteristic explaining cougar use of habitat (Logan and Irwin 1985, Laing 1988, Williams et al. 1995, Jalkotzy et al. 1999). Cougars preferred areas <10m from cover and avoided all areas >10m from cover. Van Dyke et al. (1986) found cougars avoided logged areas and suggested this avoidance may be due to reduced cover. Belden et al. (1988) and Williams et al. (1995) found cougars made extensive use of edge habitat, which provides conditions suitable for stalking cover. Cover may not only be important for cougars for stalking, but may also provide security as they move through human dominated corridors.

Distance to trails and human disturbance were included in the top regional model. My results indicated that the further away from trails and human disturbance (which is largely comprised of roads), the lower the probability was of cougar travel routes. Some studies have documented cougar avoidance of roads, trails and human use areas (Van Dyke et al. 1986, Belden and Hagedorn 1993, Beier 1995, Jalkotzy et al. 1999), while others have not shown avoidance of such areas (Laing 1988, Williams et al. 1995). Cougar use of trails is not surprising as snow-packed trails reduce energy costs during winter months (Paquet et al. 1996, Paquet et al. 2000). Cougar response to human disturbance and trails in my study may differ from other studies where cougars are from hunted populations. Jalkotzy et al. (1999) documented that cougars exposed to hunting may avoid road and trails to reduce exposure to hunters. While the home ranges of

cougars included in this study are not known, some home ranges may not extend outside the park, and hence are not exposed to hunting pressures.

While my study indicates an attraction to human disturbed areas such as trails and roads, I did not determine the time of day these areas were used (74% unknown, 22% night, 4% day). It is well documented that cougars are crepuscular animals (Logan and Irwin 1985, Van Dyke et al. 1986). Therefore, it is reasonable to assume that cougars use these areas when human activity is lowest (Duke unpubl. data, Percy unpubl. data). Van Dyke et al. (1986) reported that cougars modified activity patterns when exposed to human disturbance, with activity peaking during the night instead of at sunrise.

Cougar response to trails and human disturbance was similar to that seen for wolves. As with wolves, cougar response to human disturbance is more likely a response to other habitat characteristics within the mountainous landscape than an attraction to human disturbances. Cougars prefer steeper slopes than wolves, however, very steep slopes (>30°) are avoided by cougars. However, areas with slopes >30° are also avoided by humans and development pressures.

My results are consistent with those of Hornocker (1970), Beldan et al. (1988) and Maehr and Cox (1995), who suggest that cougars use habitat that increases their likelihood of encounters with prey. In my study, relative prey abundance was an important habitat characteristic with moderate relative prey abundance having a positive effect compared to low relative prey abundance. However, high relative prey abundance had a negative effect compared to low relative prey abundance. This may be because high relative prey abundance areas are located in areas that are relatively open with little overstory vegetative cover (e.g. Golf Course, Vermillion Lakes and Indian Grounds

Corridor) and contain highly habituated elk located in the immediate surroundings of the Banff Townsite (Woods et al. 1996). Cougar preference for areas close to cover may explain the avoidance of high relative prey locations. H. G. Shaw (Arizona Game and Fish Dep. 1980) noted that cougars seemed reluctant to follow deer to the lowest elevations of deer range even though this was where the greatest winter densities of deer occurred. Similarly, in the Greater Yellowstone Ecosystem where ungulates are abundant in grassland steppes or agricultural fields, Murphy (1998) found that cougars rarely kill prey in these areas, presumably because there is inadequate stalking cover. The need for secure habitat (cover) may override the attraction to high prey density.

My results suggest cougars can adapt to human disturbance. The adaptability of cougars has been well documented (Beier 1995, Jalkotzy and Ross 1995, Maehr and Cox 1995, Williams et al. 1995, Ruth et al. 1998). Cougars have shown an ability to negotiate roads, trails and residential areas. Maehr and Cox (1995) suggest that the Florida panther (*Felis concolor coryi*) is not strictly a wilderness animal but one that can adapt to certain landuses and ranges of human activity. Murphy et al. (1998) suggest that if cougars are repeatedly exposed to humans with no strong negative consequences, cougars may continue to use habitat where human activity is a regular feature or their environment. My results also support these findings as cougars were found using areas close to trails and human disturbance. My results show that cougars are dependent on a number of habitat characteristics as they move through human dominated corridors. Cougar response to corridor habitat characteristics is similar to cougar responses at broad, home-range scales and lends support to Rosenberg et al. (1997) comment that individual animals are more likely to select movement pathways that include important components

of their preferred habitat. Important habitat characteristics for cougars include slope, distance to cover, distance to trails, human disturbance, relative prey abundance and corridor width. This study was able to discern from this combination of habitat characteristics that cover is a particularly important characteristic for cougars in areas of close proximity to humans. Cougars prefer areas <10m from forest cover and moderate slopes. Cougars prefer areas <50m from trails and prefer areas of moderate prey abundance. These important habitat characteristics do not act exclusively but are part of a combination of habitat features that are important to cougars as they travel through human-dominated landscapes.

**Comparison of Wolf and Cougar Use of Corridors**

At the regional-scale, habitat preferences for wolf and cougar were very similar. Slope, distance to cover, distance to trails and human disturbance, relative prey abundance and corridor width were important to both wolf and cougar travel routes. Wolves and cougars responded similarly to distance to cover, distance to trails and human disturbance. While the response to distance to cover was similar, cougars showed a stronger preference for areas < 10m from cover.

The effect of slope and relative prey abundance differed between wolf and cougar responses. Cougars preferred steeper slopes, while wolves preferred flat and gentle slopes. For cougars, high relative prey abundance had a negative effect on the probability of cougar use. For wolves, high relative prey abundance had a positive effect on the probability of wolf use. These differences in habitat preferences between wolves and cougars are likely the result of differences in life history strategies between the two

species. Wolves were more apt to access open spaces of high relative prey abundance than cougars (see Figure 2-2, cougars show a stronger avoidance to greater distances to cover). Wolves showed greater variation in response to distance to cover at the individual-scale. At the individual-scale, distance to cover was included in all cougar models but only included in 57% of wolf individual models.

In BNP, big horn sheep constitute 18% of cougar diet while only comprise 8% of wolf diets (BNP unpubl data). Big horn sheep use steep, rocky terrain (Holroyd and Van Tigem 1983), which attracts cougars to these areas. Cougars also use steep terrain to stalk prey (Jalkoyzy et al. 1999) which explains greater use of steep slopes by cougars.

Wolf and cougar showed similar responses to human disturbance. However, cougar and wolf response to human disturbance is more likely a response to other habitat characteristics within a mountain landscape than an actual attraction to humans. In the Rocky Mountains animals depend on the valley bottoms, which offer the only corridors between habitat patches. Under these circumstances, animals are forced to travel through human disturbed areas or to avoid areas altogether. A comparison of wolf and cougar use of corridors in undisturbed areas would provide more useful information on the impact of humans on travel routes.

**Different types of human disturbance**

In the few studies that have systematically examined human population density and wolf distribution at broad, regional scales, it becomes clear that wolves select areas that are most remote from human influence (Paquet et al. 1996 and all cited references). However, it is difficult to distinguish between human influences such as human density,

road density and urban areas, as most influences are highly intercorrelated (Paquet et al. 1996). In an attempt to differentiate wolf and cougar response to different types of human influences, I examined the results of models that included both distance to roads and distance to high human use. High human use included roads, high use trails (>500 events/month), residential, commercial and industrial areas. Roads and high human use were correlated (Spearman rank correlation r=0.82), which is greater than the cut-off of r=0.70, which is used to eliminate the effects of multicollinearity (Tabachnik and Fidell 1996). The resulting models indicated an opposite response to high human use, than to trails and roads (Appendix 3). This may indicate some differentiation to types of human activity. Wolves and cougars were not negatively affected by trails and roads but were negatively affected by high human use. This suggests wolves and cougars respond to a threshold of human disturbance, as they appeared relatively undisturbed, and even attracted to trails and roads but avoid other areas of human disturbance which include residential, commercial and industrial areas. One explanation for this response may be that human use of trails and roads is largely temporal with highest human use corresponding with daylight hours (BNP unpub. data). Commercial, industrial and especially residential areas regularly have constant human activity, which wolves and cougars may avoid. These results should be interpretated with caution since the correlation between the two variables leads to multicollinearity (Tabachnick and Fidell 1996), which may result in the effect of one variable overriding the effect of the other. Further research investigating carnivore responses to different types of human activity is required to effectively manage human use within corridors.

**Biases and Errors**

Compositional analysis assumes that each individual sampling unit provides an independent measure of habitat use. Individual corridors were used as the sampling unit, which means that wolf and cougar use within each corridor was assumed to be independent of use within other corridors. Corridors ranged in distance to each other from <1km to >20km. It was infrequent that travel routes from one corridor linked to another corridor due to fenced highways and human developments. On 9 occasions for wolf, and 5 occasions for cougar, travel routes were linked between two adjoining corridors. In these cases, use in corridors was not independent, however these travel routes were included in the analysis to maximize sample sizes.

The use of continuous tracking trajectories to represent wolf and cougar use resulted in violation of the assumption of data independence required for multiple logistic regression (Sokal and Rohlf 1995), as each pixel along each tracking sequences was used to represent wolf or cougar use. The resulting standard error values of the beta coefficients are underestimated due to spatial autocorrelation of the data. The resulting inflated test statistic increases the chance of a Type I error (Sokal and Rohlf 1995). However, the objective of the study was to identify what combination of habitat characteristics are important to wolf and cougar travel routes in corridors using an information theoretic approach, and not to construct probability models to be used to predict wolf and cougar travel routes in corridors. Doing so, the results are still useful at determining which habitat characteristics are important for wolves and cougars in corridors.

Habitat selection is dependent on the scale of comparison and the availability of habitat (Johnson 1980). I assumed that habitat availability was equal for all animals. Without knowing the home range of individual wolves and cougars, this assumption may have been violated. Territoriality and intraspecific competition may have excluded animals from certain areas within corridors. I also assumed that all wolves and cougars had an equal chance of being detected moving through a corridor. Locations of transects, at the minimum widths of the corridors and extending the entire width of corridors, ensured that if an animal was travelling through the corridor, it would be detected. However, heavy snowfall or poor tracking conditions may have resulted in a few individual animals passing through a corridor undetected.

## CONCLUSIONS/MANAGEMENT RECOMMENDATIONS

I found that there are several habitat characteristics important for both wolf and cougar winter travel routes through corridors. Wolf and cougar preference for many habitat characteristics was similar. In order to optimize wolf and cougar use of wildlife corridors, land managers need to recognize that a combination of key habitat characteristics is required to maximize connectivity around developed areas. I found that wolves prefer flat to gentle slopes in close proximity to forest cover (<25m), the latter being particularly important in corridors adjacent to high levels of human activity. Wolves preferred areas <50m from trails. Although wolves are sensitive to human disturbance, wolves used areas close to human disturbance (<500m) when other important characteristics were present including flat/gentle slopes and high prey abundance. I found that cover was a particularly important characteristic for cougars.

They prefer moderate slopes, close to forest cover (<10m). Cougars also prefer areas <50m from trails and areas of moderate relative prey abundances. These habitat characteristics do not act exclusively but are part of a combination of habitat features that are important to wolves and cougars as they travel through human-dominated landscapes.

Discerning which habitat characteristics are important and which classes of habitat characteristics are preferred, allows land managers to identify areas that provide optimal movement opportunities for wolves and cougars around developed areas. This information can also be used to identify areas that are insufficient to act as wildlife corridors. For example, this research shows that wolves and cougars avoid open areas around human development. This suggests that areas including open meadows, golf course, ski hills and airfields do not make good corridors. These areas do not provide adequate cover required for wolves and cougars as they move through corridors. If areas such as these are to be used as corridors adequate cover should be implemented. Open areas that span greater than 10-25m should be eliminated from corridors.

I recommend that efforts be made to maintain moderate to high relative prey abundances in corridors as both wolves and cougars responded positively to increased prey abundances. Recent efforts in BNP have removed elk from areas around the Banff townsite to reduce human-wildlife conflicts and as an attempt to restore predator-prey relationships. I recommend that careful consideration take place to ensure that adequate numbers of elk remain within corridors. I also recommend that Parks Canada continue to adversively condition elk that use areas in close proximity to humans. This will reduce that attraction of cougars and wolves to these areas.

This study was unable to discern the true effects of human disturbance on wolves and cougars as they use corridors. For both species, response to human disturbance was confounded by the mountain landscape, human dominance in valley bottoms and preference for other habitat characteristics. Results did suggest a differentiation between roads and high human use with an attraction to roads and avoidance of high human use (which includes residential, commercial and industrial areas). However, these results were not statistically valid due to possible effects of multicollinearity.

In order to truly determine influences of human disturbance in corridors, future research needs to compare wildlife use in human disturbed corridors with undisturbed corridors. As habitat fragmentation continues, this will become increasing hard to do. I recommend that research on cougars and wolves at landscape scales, which include areas with less human disturbance, can give insight into the preferred habitat characteristics of these animals. Much is known regarding wolf and cougar habitat use, behaviour, and adaptation that can be used to effectively manage corridors. I recommend that previous studies be used to understand wolf and cougar responses to human activity. This information can be applied to wolf and cougar use of corridors. Most studies conducted at broad, regional scales indicate avoidance of human disturbance (Van Dyke et al. 1986, Belden and Hagedorn 1993, Beier 1995, Mladenoff 1995, Singleton 1995, Paquet et al. 1996, Mladenoff 1997, Massolo and Meriggi 1998, Jalkotzy et al. 1999). This frame of reference more adequately addresses wolf and cougar response to human disturbances as comparisons to undisturbed areas have been included. Based on these studies, and the success of the Cascade corridor restoration (Duke et al. 2001), I recommend that all human disturbance be minimized within corridors to reduce human-wildlife conflicts,

reduce the potential of human-caused mortality (management action and vehicle collisions) and increase security for wildlife. Temporal restrictions to human activity within corridors would maximize security for wildlife and reduce the potential for interactions with humans. Wolf and cougar responses indicated an attraction to trails. While this research did not address thresholds to the numbers of trails within corridors, I recommend minimizing the number of trails in each corridor to minimize human-wildlife conflicts, and to minimize the potential for wolves and cougars to become habituated to humans.

Currently we cannot differentiate the effects of different types of human disturbances. We do not know if cougars and wolves respond to one hiker the same as one biker, one group of hikers or one vehicle. This information would give insight into future human use recommendations. Investigations into wolf and cougar use of corridors throughout the year would also give better insight into the overall use of corridors.

The habitat characteristics used in this study are only a sample of the possible habitat characteristics that may be influencing wolf and cougar use of corridors. Other habitat characteristics including snow depth, solar radiation, noise and adjoining habitat patch quality or size may also be important for wolf and cougar travel routes through corridors. As spatial, digital information becomes available, investigation of additional variables may prove useful.

Information from this research can be used in other mountain communities that suffer from human development pressures to identify and maintain effective corridors for wolves and cougars. As fragmentation and habitat loss continues to dissolve landscapes into isolated habitat patches, corridors will become increasingly important. Identifying

important corridor habitat characteristics for wolves and cougars will enhance connectivity and contribute to the long-term maintenance of these species in the Rocky Mountains.

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**APPENDIX 1**

Habitat characteristic (both natural and anthropogenic) map layers were generated for all corridors for analysis of habitat utilization by wolves and cougars. All habitat layers except distance to cover were converted into NAD 83 map datum in UTM (zone 11) map projection with a 30m pixel size. Distance to cover had a 5m pixel size.

Slope

The slope layers were derived from 1:50,000 NTS topographic series digital elevation models (DEM), using the SLOPE function in Idresi GIS software. For univariate analysis, slope values were classified as flat ($0^{\circ}$ slope), gentle ($1\text{-}5^{\circ}$ ), low ($5\text{-}10^{\circ}$ ), moderate ($10\text{-}20^{\circ}$), steep ($20\text{-}30^{\circ}$) and very steep ($>30^{\circ}$).

Distance to Cover

Cover was derived by performing a supervised classification on IRS satellite imagery at a 5 metre resolution. All pixels were given a binary classification to represent cover and non-cover. All 5m pixels classified as cover were given a value of 1, all non-cover pixels were given a value of 0. IRS images were taken in May 1999. Comparison of the classification with a digital air photo showed that areas covered in water were not differentiated. Areas covered by water were reclassified using aerial photographs (1:20,000). The DISTANCE module was used in Idresi to create the distance to cover images.

Distance to Trails

The distance to trails layers were derived from 1: 20,000 ortho-corrected aerial photographs. All trails within corridors were walked with Trimble Geo Explorers using the continuous collection mode (collection of a waypoint every 3 seconds). All trail sequences were differentially corrected and exported to Idresi as line features. The DISTANCE module in Idresi was used to create all distance to trails images. For univariate analysis, distance to trails classes were 0-50m, 50-100m, 100-250m, 250-500m and > 500m.

Distance to Human Disturbance

The distance to human disturbance layers were derived from 1: 20,000 ortho-corrected aerial photographs. All residential, industrial and commercial areas were classified as human disturbance. All roads and trails that received high (>500 events per month) were included in the human disturbance images. All human disturbed areas were digitized in Map Info as polygon or line features and exported to Idresi. The DISTANCE module in Idresi was used to create all distance to human disturbance layers. For univariate analysis, distance to high human use classes were 0-50m, 50-100m, 100-250m, 250-500m and > 500m. These layers were also used to represent high human use (see Appendix 3).

Distance to Roads

The distance to roads layers were derived from 1: 20,000 ortho-corrected aerial photographs. Multiple lane highways were digitized as polygons and all secondary roads were digitized as line features. All polygon and line features were exported from Map Info to Idresi. The DISTANCE module in Idresi was use to create all distance to roads layers. All paved, unpaved, maintained, open roads that were not located within inaccessible areas were included. Inaccessible areas included the Banff Townsite core (buildings and residents). The Canadian Pacific Railway was included as a road. For univariate analysis, distance to roads classes were 0-50m, 50-100m, 100-250m, 250-500m and > 500m.

Relative Prey Abundance

Pellet transects were conducted to determine relative prey abundance in each corridor. Pellet transects were conducted once for each corridor, in the spring of 1999 or the spring of 2000. Pellet transects were oriented parallel to track transects and were spaced 500m apart and spanned the entire length of each corridor. The direction and length of each transect depended on the topography of the corridor. Transects were oriented to bisect the corridor and ran the entire width of the corridor. The number of pellet transects in each corridor depended on the length of each corridor. The number of

winter pellet groups (deer, elk, sheep, goat and moose) for each 50m interval along transects was documented.

Each 50m interval was digitized as a point feature in Map Info and assigned a pellet value. The pellet value was the number of pellet groups for all species combined. All species were combined as all species are considered prey species for both wolf and cougar (BNP unpub. data). Pellet values were square root transformed and subjected to cluster analysis (SYSTAT 8.0) to determine groupings of pellet classes. Cluster analysis (K-means, 3 groups, Euclidean distance), resulted in the following classes of relative prey abundance: low (0-2 pellet groups), moderate (3-10 pellet groups), and high (>10 pellet groups). All 50m intervals were reclassed according to the classes of relative prey abundance. Relative prey abundance images were created using interpolation in Vertical Mapper (Northwood Geoscience Ltd.) using inverse distance weighting. Three layers for each corridor were created; low, moderate and high relative prey abundance.

Corridor Width

Boundaries of each corridor were digitized in Map Info. Corridors were defined as remnant pieces of land surrounding human development that provided for movement across or through a valley around both natural and artificial barriers. Natural barriers included cliffs and steep avalanche slopes. Artificial barriers included fencing along highways, residential and commercial developments. Width was restricted by topography (<40° slopes), human development, or a 2500m cutoff from valley bottom. Areas >2500m from the valley bottom were considered to lie outside of the zone of influence of human disturbance. Corridors were masked with an elevation cut of 2000m, which was based on the maximum elevation used by both cougar and wolf across all study areas. Areas above these elevations tended to be steep rugged peaks with heavy snow cover and were not considered to be available habitat for wolves and cougars. Corridor length was determined by the extent of the human disturbance within the corridor. Generally, corridors extended a minimum distance to an adjoining valley or a maximum distance of 2500m from human development.

All unavailable areas within corridors were masked to accurately represent the available habitat to wolves and cougars. Unavailable areas included fenced areas and

buildings. Several corridors were subject to structural changes over the course of the study period (1993-2000). Structural changes included the removal/addition of facilities and fences. Available corridors were partitioned by year according to structural changes within corridors.

Corridor boundaries were digitized in Map Info and resulting polygons were exported to Idresi. An iterative process combining distance and overlay modules were used to calculate the distance algorithm from each edge. Corridor widths for all corridors ranged from 170m to 5000m.

## APPENDIX 2

Candidate Models for determining habitat characteristics important for cougar and wolf travel routes through corridors. For the Regional, Cascade, Indian Grounds, Golf, Sulphur and Two Jack, Healy North and Healy South corridors, a total of 57 models were included in the candidate set. For the Lake Louise, Field and Sunshine corridors, a total of 26 models were included in the candidate set (all models including P were excluded). Independent variables are represented by the coding outlined in Table 2-2. Multiple logistic regression models take the form $Logit(p) = \beta_o + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \ldots + \beta_iX_I$, where p= probability that the point is used, $\beta o$ = constant, $\beta i$ = coefficients for habitat characteristics and Xi = the data value for habitat characteristic i. Only $\beta i$ are outlined here.

| Model # | Variables Included in Model |
|---|---|
| 1. | S, DC, T |
| 2. | S, DC, HD |
| 3. | S, DC, P |
| 4. | S, DC, CW |
| 5. | S, T, HD |
| 6. | S, T, P |
| 7. | S, T, CW |
| 8. | S, HD, P |
| 9. | S, HD, CW |
| 10. | S, P, CW |
| 11. | DC, T, HD |
| 12. | DC, T, P |
| 13. | DC, T, CW |
| 14. | DC, HD, P |
| 15. | DC, HD, CW |
| 16. | DC, P, CW |
| 17. | T, HD, P |
| 18. | T, HD, CW |
| 19. | T, P, CW |
| 20. | HD, P, CW |
| 21. | S, DC, T, HD |
| 22. | S. DC. T, P |
| 23. | S, DC, T, CW |
| 24. | S, DC, HD, P |
| 25. | S, DC, HD, CW |
| 26. | S, DC, P, CW |
| 27. | S, DC, HD, P, CW |
| 28. | S, DC |
| 29. | S, DC, T, HD, P |

| Model # | Variables Included in Model |
|---|---|
| 30. | S, DC, T, HD, CW |
| 31. | S, DC, T, P, CW |
| 32. | T, HD, P, CW |
| 33. | DC, HD, P, CW |
| 34. | S, HD, P, CW |
| 35. | DC, T, P, CW |
| 36. | S, T, P, CW |
| 37. | DC, T, HD, CW |
| 38. | S, T, HD, CW |
| 39. | S, T, HD, P |
| 40. | DC, T, HD, P |
| 41. | S, T, HD, P, CW |
| 42. | DC, T, HD, P, CW |
| 43. | S, T |
| 44. | S, HD |
| 45. | S, P |
| 46. | S, CW |
| 47. | DC, T |
| 48. | DC, HD |
| 49. | DC, P |
| 50. | DC, CW |
| 51. | T, HD |
| 52. | T, P |
| 53. | T, CW |
| 54. | HD, P |
| 55. | HD, CW |
| 56. | P, CW |
| 57. | S, DC, T, HD, P, CW |

**APPENDIX 3**

Top Candidate Models including both distance to roads and distance to human disturbance.

Top multiple logistic regression model set comparing wolf and cougar travel routes to available habitat within corridors across at the regional scale. Multiple logistic regression models take the form *Logit(p)* = $\beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_i X_I$, where p= probability that the point is used, $\beta o$ = constant, $\beta i$ = coefficients for habitat characteristics and Xi = the data value for habitat characteristic i. Habitat characteristics are abbreviated as outlined in Table 2-2. * indicates variables excluded from the model. N/A indicates variables that were consistent across the corridor and not included in the model. Coefficient in bold indicate p>0.05

| Species | $\Delta$AIC | $\omega_I$ | $\beta_o$ | S | DC | R | T | HD | MP | HP | CW | ROC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wolf | 0.00 | .799 | 2.88 | -.039 | -.010 | -.0011 | -.0006 | .0004 | .196 | .252 | * | .666 |
| | 2.80 | .197 | 2.93 | -.039 | -.010 | -.0011 | -.0006 | .0004 | .188 | .232 | **.000** | .666 |
| Cougar | 0.00 | .737 | 2.69 | .009 | -.034 | -.0016 | -.0003 | .0002 | .352 | -.572 | -.0002 | .653 |
| | 2.08 | .261 | 2.68 | .009 | -.034 | -.0014 | -.0002 | * | .356 | -.562 | -.0002 | .652 |

# CHAPTER 3

# TRENDS IN WILDLIFE USE OF CORRIDORS IN BANFF NATIONAL PARK: THE USE OF TRACK TRANSECTS TO MONITOR MULTIPLE SPECIES

## INTRODUCTION

In the Central Canadian Rocky Mountains, steep, rugged terrain is not conducive to the movements of most wildlife. The mountainous terrain is characterized by extremes in elevation, slope, climate and vegetation that restrict most wildlife species to the narrow, montane valley bottoms and low elevation passes (Heuer 1995, Paquet et al. 1996). The Bow Valley of Banff National Park (BNP) is an important movement corridor that links the Mountain Cordillera of Canada with the Northern United States, allowing the connection of metapopulations. The lower Bow Valley is composed primarily of montane habitat, which is rare in the Rocky Mountain ecosystem (Holland and Coen 1983), and highly valued for its ability to support a high diversity of wildlife species (Holroyd and Van Tigem 1983). This montane habitat becomes increasingly important during the winter months when wildlife are restricted to the low elevation valley bottoms due to deep snow at higher elevations.

Human development in the Bow Valley exacerbates the already confined nature of the mountain landscape, resulting in a fragmented landscape that blocks wildlife movement between patches of high quality habitat (Purves et al. 1992, Paquet 1993, Heuer 1995, Paquet et al. 1996, Heuer et al. 1998, Serrouya 1999, Duke 2000, Gibeau 2000). This exclusion may be leading to imbalances in predator-prey dynamics that, in turn, are impacting local vegetation communities (Nietvelt 2001).

Corridors located in the Bow Valley offer the only movement opportunities for wildlife as they travel through the valley. Movement is one of the most crucial life processes for wildlife. Daily and seasonal movements, dispersal and long-distance range shifts permit access to important resources, provide escape routes, and facilitate the exchange of genetic information. Without corridors to join pockets of habitat, the survival of species becomes threatened, possibly leading to local extinctions. Woodley and Theberge (1992) identify the fragmenting effects of human development as the most serious threat to the ecological integrity of Canada's National Parks.

Concern over habitat fragmentation in BNP prompted a survey of animal movements around key areas of residential and commercial development, fenced highway interchanges, golf courses, ski areas and recreational areas - to assess whether large mammals are still able to move around these obstructions (Heuer 1995). Since 1993, the Banff Wildlife Corridor Project has monitored winter wildlife movements around developed areas in BNP to determine species occurrence and frequency of use. This is the only research project in BNP that monitors multispecies movements around human disturbances and has been instrumental in identifying important corridors (see Chapter 2) for large carnivores as they negotiate their way around human obstructions.

Research findings from the Banff Wildlife Corridor Project (Heuer 1995, Stevens and Owchar 1997, Heuer et al. 1998, Duke 1999a, Duke 1999b, Duke 2000) have led to recommendations to increase security for wildlife as they travel through corridors. A strategic goal for the current Banff Park Management Plan is "to restore and maintain secure, essential movement corridors in the park, particularly in relation to the Town of Banff…" (BNP Management Plan 1997). Management actions have resulted in corridor

restorations, closures and human use restrictions within corridors. Specifically, in the fall of 1997, restoration of the Cascade Corridor was initiated to enhance wildlife movements through this corridor. Restoration of the corridor included the removal of government and public horse barns and corrals, a buffalo paddock, decommissioning of an airstrip, and relocation of an army cadet camp. In response to increased housing developments in the Sulphur Corridor in 1997, a wildlife closure was implemented that restricted all human activity. Additional management actions that contribute to increasing security for wildlife movements through corridors include the designation of the Fairholme-Carrot Creek Bench as an environmentally sensitive area and a winter vehicle restriction for the Golf Course Road, which was implemented in the fall of 1998.

Long-term monitoring of wildlife corridors allows trends in use to be identified. Trends occurring in individual corridors may indicate local-scale responses which reflect small-scale movement patterns. Decreasing movement trends may indicate corridor alterations that inhibit connectivity, while increases may indicate corridor improvements that enhance connectivity. Trends occurring across several corridors may indicate regional-scale changes in populations. The magnitude and variability of current trends also allows predictions of future trends in movement and populations (Reed and Blaustein 1997). With the exception of wolves, lynx, black bears and grizzly bears (Paquet 1993, Paquet et al. 1996, Apps 1999, Serrouya 1999, Gibeau 2000) little information exists in BNP regarding both local-scale movement trends and population trends for other wildlife species.

We used occurrence of winter tracks along transects to determine large mammal use of corridors. Track transects have been used to monitor movement or populations

trends of wildlife including cougars, boreal mammals, river otters, marten, lynx, wolves, deer, elk and sheep (Van Dyke et al. 1986, Reid et al. 1987, Thompson et at 1989, Smallwood and Fitzhugh 1995, Beier and Cunningham 1996, Alexander and Waters 1999). Track transects are an effective and efficient method to monitor trends of wildlife movement, especially during winter months when snow cover allows continuous monitoring. Other monitoring techniques include radio-telemetry, mark-recapture and direct observations. These techniques tend to be expensive, laborious, intrusive to wildlife and applicable for only short periods of time over small areas (Kutilek et al. 1983).

The use of confidence intervals to determine the significance of trends, and their importance as an alternative to hypothesis testing has been proposed by numerous authors (Hayes and Steidl 1997, Steidl et al. 1997, Thomas 1997, Gerard et al. 1998, Johnson 1999). Criticisms concerning the utility of null hypothesis testing has increased in recent years (Burnham and Anderson 1998, Johnson 1999, Anderson et al. 2000). Traditional null hypothesis testing uses an arbitrary fixed $\alpha$-level that classifies results into biologically meaningless categories of significant and non-significant (Anderson et al. 2000). This approach is relatively uninformative as null hypotheses are almost invariably known to be false before data are collected (Johnson 1999). Confidence intervals provide information regarding the true size of a trend and its uncertainty, compared to the dichotomous output from hypothesis tests that simply indicate significant differences from zero (Steidl et al. 1997, Johnson 1999). This quality of confidence intervals makes them useful to distinguish between statistical and biological significance (Gerard et al. 1998). A trend that is large enough to be considered statistically significant may not

necessarily be biologically significant and vice versa. For example, a 20% decline in population for a species may be statistically significant, but will be considered biologically significant depending on current population status. If that species is endangered or rare, a 20% decline may be the demise of the species. However, if the species is abundant or over-populated, a 20% decline may not be considered biologically significant. It would be advantageous to have species-specific and situation-specific criteria for estimating biological significance of trends. However, true biological significance is difficult to determine and will vary depending on the question being asked (Hayes and Steidl 1997, Reed and Blaustein 1997).

Scientists have difficulty determining what constitutes a biologically significant trend size (Reed and Blaustein 1997, Gerard et al. 1998). However, predicting trend sizes thought to be biologically significant, or a range of potentially significant trend sizes is critical in biological research (Hayes and Steidl 1997). Biologically significant rates of decline vary among species and will vary among populations and situations (Reed and Blaustein 1997). One of the most useful features of confidence intervals is that results are portable. Researchers who do not agree on the same criteria for biological significance can still use the results for their own purposes (Gerard et al. 1998). Managers should not necessarily wait for trends to be statistically significant before initiating a management response (Reed and Baustein 1997). Based on current trends, managers can project ranges of future trends they consider to be important. This allows managers to respond to both local-scale and population-level trends before irreversible events take place, such as alienation or local extinctions.

**Objectives**

The purpose of this study was to report on the 8-year investigation into the occurrence of tracks of large mammals in corridors located in Banff National Park. I wanted to determine trends in species use during the study period. I also wanted to determine if the use of track transects was an effective method to determine both local-scale movement and population-level trends. My objectives included the following:

1) For each species, determine if track transects are an effective method to monitor trends in corridor use.
2) For each species, determine which corridors resulted in significant local-scale movement trends.
3) Determine which species showed population-level trends.

To achieve my objectives, transects were monitored in seven different corridors over an eight year period. Data from these transects were transformed to a standardized crossing index. Crossing index trends were calculated for each transect using linear regression relationships. Trends were compared across transects by species to determine for which transects both statistical and biologically significant trends were detected. This study will determine if track transects are an effective method to monitor trends of wildlife use of corridors and will assess local-scale and population-level trends. Wildlife managers will be able to integrate this information into their monitoring programs as they strive to manage wildlife corridors for the maintenance and enhancement of wildlife movements through the Bow Valley of BNP.

## METHODS

### Study Area

Banff National Park (BNP), 6641km$^2$, is located along the eastern slope of the Continental Range of the southern Canadian Rocky Mountains, about 110 km west of the city of Calgary, Alberta. BNP is characterized by extreme mountainous topography. Habitat within BNP is montane, subalpine, or alpine depending on elevation. Low elevation montane is the most productive and biologically diverse habitat found within BNP, yet only accounts for 3% of the area (Holroyd and Van Tighem 1983). Approximately 82% of BNP's montane habitat is within the Bow River Valley (Holroyd and Van Tighem 1983). Seven different corridors were monitored in the Bow Valley. Corridors provided movement opportunities around both natural and artificial barriers. Natural barriers included cliffs and steep avalanche slopes. Artificial barriers included fencing along highways, residential and commercial developments. All corridors are located within a five kilometre zone surrounding the Banff Townsite. All corridors except the Sunshine corridor are located in montane habitat. The Sunshine corridor is located in sub-alpine habitat in a side valley of the Bow Valley. One transect was located in each corridor except for the Cascade Corridor which had two transects. All corridors link habitat surrounding areas of human disturbance including residential and commercial areas, a golf course, highways, parking lots and a ski hill. Corridors range in size from 1.98 km$^2$ to 13.04 km$^2$.

**Data Collection**

Transects were monitored to document wildlife movement through corridors. Transects were oriented to bisect the most likely directions of wildlife movements through corridors and, where possible, were located at the most constricted portion of each corridor. The eight transects monitored included the following: Airfield, Sulphur, Golf Course, Indian Grounds, Penstock, Vermillion, Healy North and Sunshine. All transects were monitored for eight winters (1993-2001) except for the Healy North and Penstock transect, which were monitored for five winters each (1995-2001). Transects were divided into 100m intervals and all intervals were marked with flagging tape. Transects were monitored from November 1 to April 15 each winter, as snow allowed. Transects were sampled a minimum of 12 hours after snowfall. In the absence of new snow, transects were monitored after three days, ensuring that only new tracks were documented. Number and direction of tracks were documented for the following species: moose (*Alces alces*), elk (*Cervus elaphus*), white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), bighorn sheep (*Ovis canadensis*), mountain goat (*Oreamnos americanus*), mountain caribou (*Rangifer tarandus*) wolf (*Canis lupus*), coyote (*Canis latrans*), cougar (*Puma concolor*), grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), and lynx (*Felis lynx*). Only those tracks that crossed the transect itself were counted. Due to the difficulty in distinguishing between white-tailed deer and mule deer, both were classified as deer. Crossings from large carnivores documented from other researchers were included in the crossing index. The sampling period for these samples was calculated from the approximate age of tracks. Results for elk, deer, sheep,

coyote, wolf and cougar are included in this chapter. All other species were absent or sample size was too small to be included.

## Statistical Methods

Transect crossings were standardized using a crossing index. The crossing index was calculated by dividing the total number of transect crossings for each species by the number of 12 hour periods since snowfall (or since sampling), divided by the length of the transect. All indices were multiplied by 1000 for ease of computation. A crossing index was calculated for each species, each time the transect was sampled. Crossing indices were used to determine trends in use of each transect by calculating linear regression relationships for each transect over the 8 year period. (Hayes and Steidl 1997, Nickerson and Brunell 1997). The slope of the linear regression indicated the trend of the crossing index data. Confidence intervals (95%) were determined for each transect trend. Observed trends and their associated confidence intervals were plotted for all transects by species.

Previous research in BNP investigated the response of radio-collared wolves to corridor restoration in the Cascade Corridor (which includes the Airfield and Vermillion transects) (Duke et al. 2001). Response was evaluated by comparing two winters of post-restoration movements with four years of pre-restoration movements. Wolf use of the corridor, as measured by number of wolf radio-telemetry days and transect crossing indices, was significantly higher after corridor restoration (10-fold increase). Due to the magnitude of this response, I considered it to be biologically significant and used this response as a guideline of biological significance. Using crossing indices, wolf use of the

Airfield transect from 1993-2000 resulted in a trend of 0.11 (see Figure 3-1). The biologically significant level used in this study was calculated for wolves and was applied to other species although it may not be appropriate for other species. However, the trends and associated confidence intervals presented here can be used for any determined level of biological significance.

Confidence intervals surrounding the trend of each transect were used to determine not only if a trend occurred, but to determine if trends were large enough to be considered biologically significant. Confidence intervals for the observed trend that overlap zero indicate no significant trend. Confidence intervals for the observed trend that do not overlap zero indicate a significant trend. If the observed trend and associated confidence intervals lie entirely outside of the minimum biologically significant range we can conclude that there was no biologically significant trend (Steidl et al. 1997). An observed trend with associated confidence interval that only contains biologically meaningful values leads to the conclusion of biological significance (Steidl et al. 1997, Gerard et al. 1998).

## RESULTS

Over the study period, transects were sampled between 7 and 27 times per year (Table 3-1). The number of times sampled per year depended on snow fall and available manpower. Results indicate that wolf and cougar showed increasing movement trends over the study period while deer, coyote and sheep showed overall decreasing trends. Elk crossing indices were highly variable and hence trends were unreliable. Figure 3-2

presents the observed trend and associated confidence intervals for each transect by species. Both statistically significant and biologically significant responses are reported.

Table 3-1. Transect summary. Number of times each transect was sampled throughout the study period (Winters 1993-2001).

| | Number of times sampled per year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Transect | 93/94 | 94/95 | 95/96 | 96/97 | 97/98 | 98/99 | 99/00 | 00/01 |
| Airfield | 11 | 9 | 17 | 19 | 18 | 13 | 7 | 10 |
| Sulphur | 12 | 11 | 23 | 24 | 15 | 14 | 15 | 12 |
| Golf Course | 9 | 10 | 17 | 20 | 12 | 13 | 11 | 8 |
| Indian Grounds | 9 | 7 | 14 | 15 | 15 | 16 | 10 | 13 |
| Penstock | N/A | N/A | 19 | 16 | 16 | 11 | 10 | 9 |
| Vermillion | 10 | 11 | 16 | 18 | 15 | 16 | 10 | 11 |
| Healy North | N/A | N/A | 19 | 27 | 17 | 11 | 7 | 9 |
| Sunshine | 9 | 12 | 15 | 15 | 15 | 13 | 15 | 9 |

Deer

Deer show an overall decreasing trend in use of transects. Seven transects indicate a decreasing trend and one transect indicates an increasing trend in deer use. The Sulphur, Vermillion and Healy North transects resulted in a statistically significant decrease, with the Sulphur transect indicating a biologically significant decreasing trend. All other transects resulted in non-significant trends. Deer trends ranged from 0.013 to -.398.

Sheep

Results for sheep show an overall decreasing trend in use of transects. The Healy North, Vermillion and Sunshine transects indicate statistically significant decreasing

trends. Sheep were not observed on the Sulphur, Indian Grounds, and Penstock transects due to unsuitable habitat. Sheep trends ranged from -.0044 to -.174.

Elk

Elk response was variable across transects. Six transects indicate a decreasing trend and two transects indicate an increasing trend. Confidence intervals for all transects except the Airfield and Vermillion overlap zero indicating no significant trend in elk use. The Airfield and Vermillion transects indicate a significant decreasing trend. The decrease seen on the Airfield transect was a biologically significant decrease. Most transects resulted in wide confidence intervals indicating large variation in elk responses. Elk trends ranged from 0.646 to -1.010.

Coyote

Results for coyote show an overall decreasing trend in use of transects. Seven transects showed a decreasing trend. Five decreasing trends were statistically significant and one of these, the Indian Grounds transect, was biologically significant. Two transects resulted in a non significant decreasing trend and one transect resulted in an non significant increasing trend. Coyote trends ranged from .055 to -.377.

Cougar

Results for cougar show an overall increasing trend in use of transects. Five transects indicate a significant increasing trend and three transects indicate a non-significant increasing trend. No transects resulted in a biologically significant trend. Cougar trends ranged from .013 to .067. Figure 3-3 (from Hebblewhite 2001) outlines the number of cougar and wolf kills in the Central Zone of the Bow Valley which includes all

transects except the Sunshine transect. The number of cougar kills have increased in the Central Zone in the Bow Valley from 1993-2000.

Wolf

Wolf response was variable across corridors. Five transects indicated an increasing trends and two transects indicated a decreasing. The Indian Grounds transects indicated a statistically and biologically significant increasing trend. The Airfield, Golf Course and Vermillion transect indicated a statistically significant increasing trend. The Penstock transect resulted in a statistically significant decreasing trend of wolf use. Confidence intervals for all other transects overlapped zero indicating no significant trend in wolf use. Wolf trends ranged from .551 to -.317. The number of wolf kills have increased in the Central Zone in the Bow Valley from 1993-2001 (Figure 3-3).

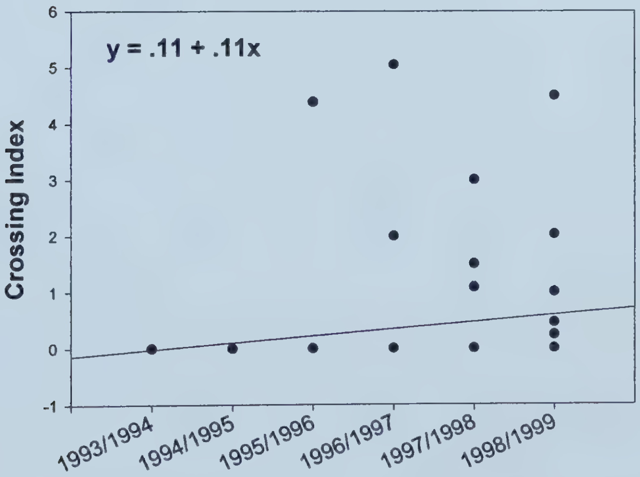
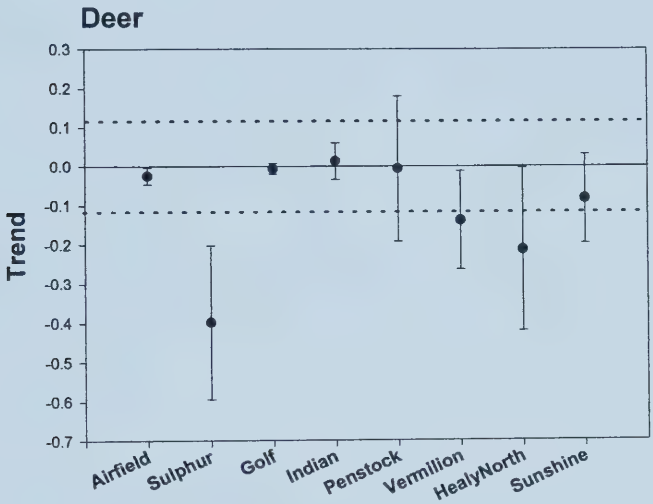



Figure 3-1. Relationship between wolf crossing indices and year for the Airfield transect (Winters 1993-1999). This relationship (slope = 0.11) was used as an indicator of biological significance. Previous research (Duke et al. 2001) showed that wolf use of the area significantly increased between 1993-1997 and 1997-1999.

Figure 3-2. Transect trends. Trends represent the linear regression relationship (slope) between crossing indices and year. For all transects, sampling period includes winters of 1993-2001, except Healy North and Penstock which were sampled 1995-2001. Dashed lines indicate minimum biologically significant values.



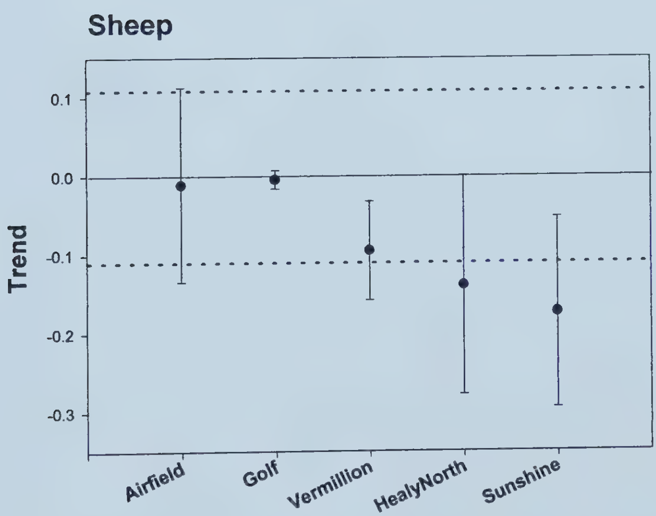
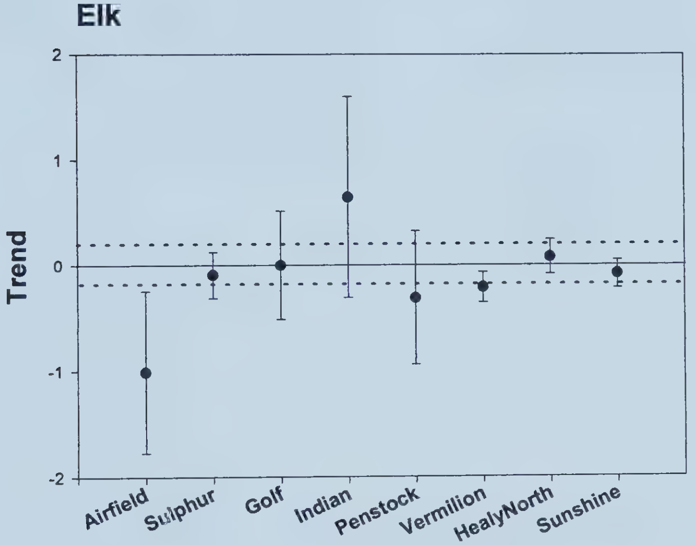



Figure 3-2 cont'd. Transect trends. Trends represent the linear regression relationship (slope) between crossing indices and year. For all transects, sampling period includes winters of 1993-2001, except Healy North and Penstock which were sampled 1995-2001. Dashed lines indicate minimum biologically significant values.



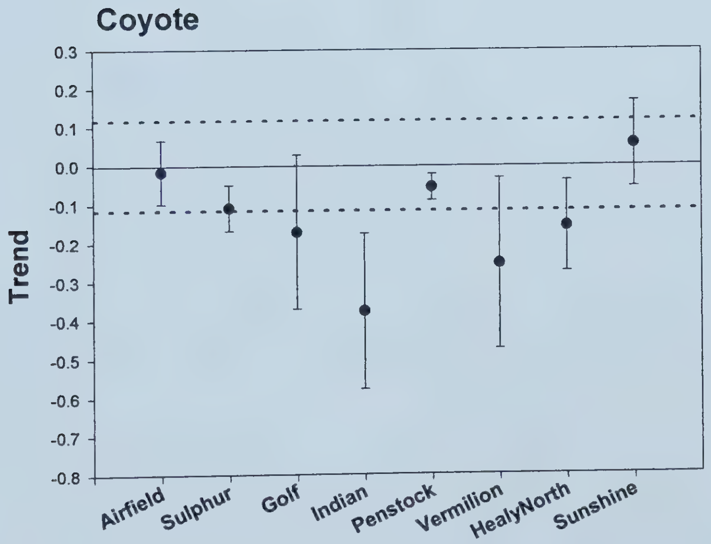
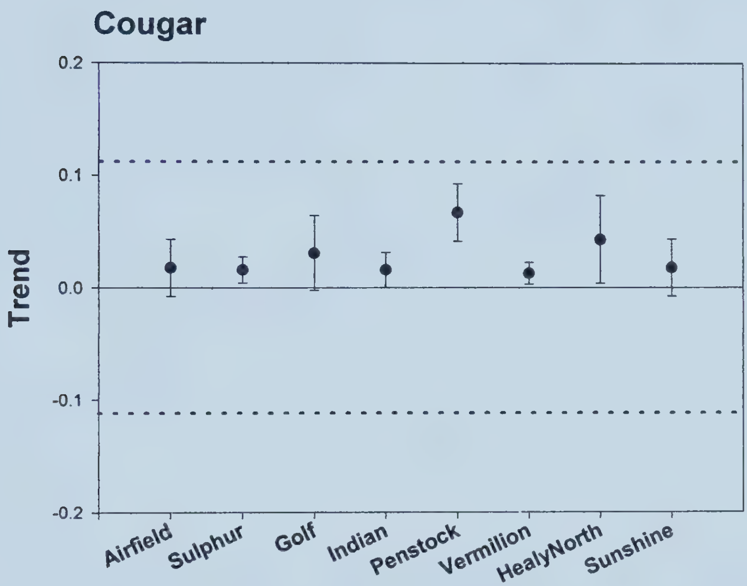
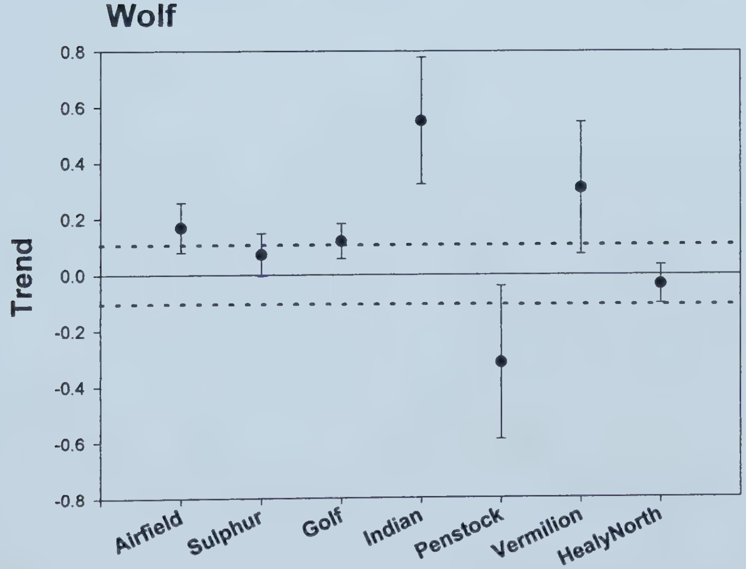



Figure 3-2 cont'd. Transect trends. Trends represent the linear regression relationship (slope) between crossing indices and year. For all transects, sampling period includes winters of 1993-2001, except Healy North and Penstock which were sampled 1995-2001. Dashed lines indicate minimum biologically significant values.



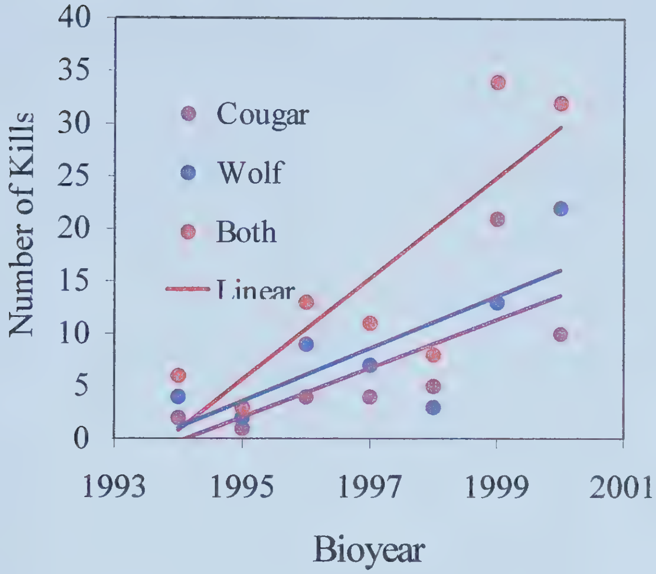



Figure 3-3. Number of predator kills (all ungulates combined) in the Central Zone of the Bow Valley from 1993 to winter 2001 (up to February 1, 2001). The Central Zone includes all transects except the Sunshine transect. Bioyear is defined as the biological year from May 1st to the following April 30th (From Hebblewhite 2001).

## DISCUSSION

My results indicate that the use of track transects to monitor trends in wildlife movements through corridors is more effective for deer, sheep, coyote, cougar and wolf than for species such as elk. The large variation surrounding elk responses suggests this is an unreliable method to determine elk trends (see Figure 3-2). The variation surrounding the elk response was 3-95 times greater than the variation for all other species. Accurate counts of the number of individual elk crossing each transect is difficult to determine and the counts fluctuate over a wide range leading to large variation in crossing indices. This large variation in crossing indices leads to inaccurately inflated trends. Elk counts often ranged from 0 to over 100 crossings per sampling period.

The only significant elk response was seen on the Airfield and Vermillion transects. The Airfield response was both a statistical and biologically significant decrease, while the Vermilion response was a statistically significant decrease. These results support the findings of Duke et al. (2001), who found that increased wolf use of the Cascade Corridor (which includes the Airfield and Vermillion transects) could not be attributed to increased elk use of the corridor. The decreasing elk trend seen on the Airfield and Vermillion transects can most likely be attributed to the recent management actions that have reduced elk numbers around the Banff Townsite. Park management removed 50 elk in 1998, 173 in 1999 and 30 elk in 2000 to reduce the number of human-elk conflicts and to restore predator/prey relations in the Bow Valley (BNP unpub. data). In addition, since 1999, elk within the Banff Townsite periphery have been subjected to intensive adversive conditioning to discourage use in the town core areas. This has

resulted in artificial movement trends throughout the study area. However, trends seen for elk are inconclusive due to the large variation seen for all transects, which suggests that tracking is not an effective method for determining elk movement and population trends.

The use of track transects was more effective for monitoring deer than elk. Variation of deer trends was 4-10 times less than for elk. Reduced variation for deer is due to the smaller number of deer tracks crossing transects. Deer counts rarely exceeded 20 crossings per sampling period. Significant decreasing trends were seen on the Airfield, Sulphur, Vermillion and Healy North transects, and non-significant decreases were seen on the Pentock and Sunshine transects. This overall decreasing trend suggests a population-level decrease in the Bow Valley. Previous research showed a significant decrease in deer pellet abundance in the Bow Valley between 1979 and 1998 (Hurd 1999). ) Prior to 1979, wolves were absent from the Bow Valley since the 1950's, and did not recolonize until the early 1980's (Paquet 1993). The continued decreasing trend in deer use may be explained by the increasing trend of wolf and cougar use of corridors (see below). However, wolf kill rates for deer in the Bow Valley from 1987/1988 to 1999/2000 do not significantly increase (Hebblewhite 2000b). Deer comprise 22% of wolf diets and 43% of cougar diets (BNP unpublished data, 1987/88-1999/2000).

Trends for deer also showed a local-scale change in movement probably resulting from a management action. No transect showed a decrease as significant as the Sulphur transect. In 1997, the Middle Springs subdivision, located in the Sulphur corridor, expanded. This development reduced the width of the corridor by 400m, at it's narrowest point, thereby reducing the habitat available for deer. This may explain the local-scale decreasing movement trend

Previous coyote research in BNP focused on coyote use of urban areas (Gibeau 1993), but little information exists regarding coyote movement or population trends over time. My results indicate an overall decreasing trend in coyote use across all corridors. The decrease in coyote use seen on the Airfield, Sulphur, Golf Course, Indian Grounds and Vermillion transects corresponds to an increase in wolf use on the same transects. A highly significant increase of wolf use in the Indian Grounds corridor corresponds with a highly significant decrease of coyote use. This movement trend can be attributed to the Fairholme wolf pack (see below). Prior to 1999, wolves rarely used the Indian Grounds Corridor. Since 1999, 2-9 wolves have used this corridor with increasing frequency (Duke 2000, Hebblewhite 2001). It is well known that wolves and coyotes compete for food resources and wolves are known to kill coyotes (Carroll et al. 2000). Coyotes killed by wolves in BNP have been documented on 4 occasions since 1992 (BNP unpub. data), including one in the Sulphur Corridor in 1998. Coyote numbers in Yellowstone National Park have declined since the re-introduction of wolves in 1995 due to direct competition with wolves (Crabtree and Sheldon 1998). Increasing trends of wolf use in corridors (see below) around the Banff townsite may result in decreases in coyote use in the future. The overall decreasing trend seen across seven transects may suggest that the coyote population is decreasing in the Bow Valley. Currently no research in BNP focuses on coyotes.

Little information exists regarding cougars in BNP. Cougars have been documented in the park since its inception in 1885 and sightings are documented on an infrequent basis (Holroyd and Van Tigem 1983). The only information pertaining to cougars comes from trends obtained from tracking data and cougar use of highway

crossing structures (Gloyne and Clevenger 2001). Recent speculation has cougar use of areas around the Banff townsite increasing. The number of cougar kills around the Banff Townsite has increased in recent years (see Figure 3-3) and reports of cougar sightings have also increased (BNP unpublished data). Gloyne and Clevenger (2001) report that cougar use of highway underpasses has increased from 1997 to 1999. However, it is unknown if the cougar population in BNP is increasing or if use of certain areas has increased. My results suggest an overall increasing trend in cougar use of across all corridors. Trends were generally smaller for cougars than for other species. This is due to the fact that cougars are solitary animals resulting in fewer transect crossings than species such as wolves that travel in groups. A biologically significant response of 0.11, which was used as an indicator derived from wolves, may be too high to account for important cougar trends. This overall increasing trend across corridors suggests a population-level increase in cougars in the Bow Valley over the last 8 years. However, twelve cougars have been removed from the Bow Valley between January 2000 and March 2001. One adult female cougar, with three kittens, was killed on the highway and the kittens removed from the park. Four cougars were shot as a result of conflicts with humans. One was killed by wolves, and her kitten subsequently starved, and two cougars died of natural causes (BNP unpub. data). These removals may result in decreasing trends in the future.

Wolves recolonized the Bow Valley in the 1980's after a >30 year absence (Paquet 1993). During the study period, three wolf packs had home ranges that encompassed the study area. Since 1993, the Bow Valley wolf pack, ranging in numbers from 2-9, has occupied territory to the west of the Banff townsite and frequently used

areas including the Sulphur and Healy North transects. Rarely did this pack use areas surrounding and to the east of the Banff townsite. Since 1993 numbers in this pack have declined due to highway and railway mortalities (Robertson 1999, Hebblewhite 2000b). The Cascade wolf pack was formed in 1991 from a disperser from the Bow Valley pack. From 1991-1997, this pack centered it's home range activities in the Cascade Valley and the Bow Valley east of the town of Banff, frequently using the Penstock transect and occasionally using the Cascade Corridor. This pack rarely utilized transects surrounding the Banff townsite. Numbers in this pack have ranged from 6-18 (Hebblewhite 2000b). In 1997, this pack expanded it's home range to includes areas further north in the park (Duke et al. 2001). Since this time, this pack has infrequently used the Bow Valley. The Fairholme wolf pack was formed in 1999 and has centered its movements around the Banff townsite and areas east to the town of Canmore (Hebblewhite 2000a). In 1999, there were two individuals and in 2000, nine wolves. This pack utilizes all transects surrounding the Banff Townsite. Wolf pack dynamics and territory shifts of the three wolf packs can largely account for trends in corridor use in the Bow Valley.

In 1995, based on findings from previous research (see Paquet et al. 1996), the Banff Bow Valley Study (Green et al. 1996) recommended the restoration of the Cascade Corridor. During 1997, management actions reduced human use within the Cascade Corridor to a level predicted to increase wolf movement. Restoration of the corridor included the removal of Parks Canada horse corrals and public corrals, a buffalo paddock, decommissioning of an airstrip and relocation of a cadet camp. The response of radio-collared wolves to corridor restoration was evaluated by comparing two winters of post-restoration movements with four years of pre-restoration movements. Wolf use of

the corridor, as measured by number of wolf radio-telemetry days and transect crossing indices, was significantly higher after corridor restoration. Careful consideration of other potential confounding effects failed to offer alternative explanations for the increased use (Duke et al. 2001). My results, which indicate an increase of wolf use on the Airfield and Vermilion transects support the findings of Duke et al. (2001). The restoration of the Cascade Corridor may also be a contributing factor to the increase in wolf use seen on the Indian Grounds transect (see below).

The increase in wolf use of the Airfield, Golf Course, Indian Grounds and Vermillion transects is due to the Fairholme wolf pack. Since the inception of this wolf pack, wolf movements around the Banff townsite have dramatically increased (Duke 2000, Hebblewhite 2000a, Hebblewhite 2001). Prior to the Fairholme pack, wolves infrequently used the corridors surrounding the Banff townsite (Heuer 1995, Stevens and Owchar 1996, Paquet et al. 1996, Heuer et al. 1998, Duke 1999a, Duke 1999b, Duke 2000), and rarely linked corridors as a means to circumnavigate the Banff townsite (Heuer et al 1998, Duke 2000). However, the Fairholme pack regularly uses all transects surrounding the town, linking the use of corridors. Of the 11 wolf tracking sequences that link corridors (see Chapter 2), 9 have been made by the Fairholme pack. The number of wolf kills located in corridors surrounding the Banff townsite has also increased since the formation of the Fairholme wolf pack (Figure 3-3).

The decreasing trend of wolf use on the Penstock corridor can be attributed to the territory shift of the Cascade Pack. The Penstock transect is located in the Fairholme bench just east of the Banff townsite, north of the highway. From 1993-1997, the Cascade pack would frequent this area during winter months as they followed elk herds

to the montane Bow Valley. In the summer and fall of 1997, the Cascade pack expanded its home range to include areas further north in BNP (Duke et al. 2001). Since this time, the Cascade pack has not utilized areas near the Banff townsite. The Penstock transect is still utilized by the newly formed Fairholme pack but the fewer wolves of the Fairholme pack accounts for the decreasing trend. If crossing indices for wolf had been calculated at a pack-level, no decrease would have been detected. Total number of animals were used to calculate crossing indices to keep the crossing index consistent across species and also because many transect crossing were made by lone wolves. Lone wolf movements are important to include as they indicate possible dispersal movements. In addition, while wolves are pack animals, there is much individuality among pack members (P. Paquet pers. commun). If some members of a pack utilize a corridor, and others do not, this may be an indication of avoidance. Calculating crossing indices using total numbers give a better indication of true corridor use.

Increases in predator (cougar and wolf) use around the Banff townsite are most likely due to population increases as seen by increasing trends across corridors. Increases may also be attributed to recent management actions, including restorations and human use restrictions that have increased predator security in corridors. This increased security for wildlife enhances connectivity and allows predators access to elk herds that frequent areas around the Banff Townsite (Woods et al. 1996). Continued use of corridors by cougars and wolves around the Banff Townsite may contribute to reducing numbers of elk surrounding the Banff area. Repoductive success of the Fairholme pack (6 pups in 2000, 6 pups in 2001, BNP unpub. data) indicates that wolf use of areas surrounding the

Banff townsite may continue to increase, while use of areas west of Banff may remain at current levels or decrease, as the Bow Valley's wolf pack numbers remain low.

**Biases and Errors**

Linear regression is an effective technique to investigate long-term trends (Hayes and Steidl 1997, Nickerson and Brunell 1997). However, in order to investigate shorter-term trends, which may be more reflective of short-term management actions such as restorations and changes in wolf distributions, trends may be better captured and analyzed using shorter time steps such as differences between annual means or 3 year running means. Results from this study area most effective at identifying long-term trends of corridor use.

Linear regression requires that samples along the regression line have equal variances (Sokal and Rohlf 1995). My data violated this assumption, however, results from the linear regression were used to determine trend sizes (using slope coefficient) and not to develop predictive models. All of the data had the same distribution, so any bias introduced by unequal variances was consistent across all transects. The resulting standard errors and 95% confidence intervals will be larger due to unequal variances (Sokal and Rohlf 1995).

Caution should be taken when interpreting population-level trends. While consistent trends across corridors may indicate population-level trends, the frame of this study only encompasses the Bow Valley immediately surrounding the Town of Banff. The study area is contained within a single average individual home range of each species. This is particularly problematic for species such as cougars and wolves that travel long distances and have very large home ranges. Information from radio-collared

animals from other research projects, snow-tracking and observations ensured that many more than one individual animal was utilizing the study area. However, transects with a greater dispersion would more accurately identify population-level trends. All population- level trends refer to a restricted area in the lower Bow Valley, immediately surrounding the Banff townsite area.

## CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

I found the use of track transects to monitor wildlife movements through corridors to be an effective technique for deer, sheep, coyote, wolf and cougar. I found that the use of track transects to monitor movement trends of elk to be ineffective. Animals that travel in large numbers, such as elk, result in highly variable and inaccurate crossing indices. In areas that receive regular snowfall, track transects are an effective, unobtrusive, inexpensive method to monitor movement trends of most wildlife species. Snow-tracking of target species from track transects is a useful technique for other research objectives including predator-prey relationships, and movement patterns (see Chapter 2). I recommend the continued use of track transect to monitor multi-species use of transects in BNP.

I found overall decreasing trends for deer, sheep, coyote and increasing trends for cougar and wolf. Decreases in deer may be due to increases in predator (cougar and wolf) use of corridors and coyote decreases may be due to increased competition with wolves. Increases in predator use around the Banff townsite is likely due to increases in populations, as seen by the overall increasing trends across corridors. Increases, such as the wolf response on the Airfield and Vermillion transects, may also be attributed to

recent management actions, including restorations and human use restrictions that have increased predator security in corridors. This increased security for wildlife enhances connectivity and allows predators access to elk herds that frequent areas around the Banff Townsite. Continued use of corridors by cougars and wolves around the Banff Townsite may contribute to reducing numbers of habituated urban elk. Local-scale movement trends were seen for deer on the Sulphur transect due to habitat loss. Movement trends were also seen for wolves due to pack dynamics and territory shifts.

BNP lacks accurate data regarding human use in corridors. In order to determine the impact of human use restrictions and other human-use management actions, previous levels of human activity need to be available to compare to post-treatment responses. In order to determine cause and effect relationships between management actions and wildlife responses, numerous additional environmental factors (such as habitat quality, climate factors etc.) must be examined in addition to wildlife responses. Recognizing trends in corridor use gives insight into the connectivity of the landscape and allows managers to determine areas that require further research and management.

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# CHAPTER 4

## GENERAL CONCLUSIONS

Habitat fragmentation has resulted in the loss of physical habitat and reduced connectivity for wildlife in the Central Canadian Rockies (Paquet et al. 1996). Corridors can reduce the adverse effects of habitat fragmentation by providing movement opportunities around developed areas (O'Donnel 1991, Saunders and deRebeir 1991, Beier 1995, Dunning et al. 1995, Odette and Thomas 1996). As human development expands in the Rocky Mountains and habitat fragmentation increases, it will become increasingly important for corridors to connect animal sub-populations.

Concern over habitat fragmentation in the Bow Valley of Banff National Park prompted a survey of animal movements around key areas of residential and commercial development, fenced highway interchanges, golf courses, ski areas and recreational areas, to assess whether large mammals were still able to move around these obstructions. Since 1993, winter tracking of wolves and cougars has resulted in the identification of important corridors that facilitate movement. In order to maintain and enhance movements through corridors, it is necessary to determine which classes of habitat characteristics wolves and cougars prefer, and which combination of habitat characteristics are most important for these species as they travel through corridors.

Using a geographic information system (GIS), and an information theoretic approach (Burnham and Anderson 1998), I compared the habitat characteristics of snow-tracked wolf and cougar travel routes within corridors, with habitat characteristics of available habitat at two spatial scales. A regional-scale analysis combined corridor use

across 10 different corridors for wolves and 8 different corridors for cougars. An individual-scale analysis examined wolf and cougar use in each individual corridor.

At the individual-scale, importance of habitat characteristics was dependent on the amount of availability of each habitat characteristic within individual corridors and did not reflect the overall use of corridors by wolves and cougars. At the regional scale, I found that slope, distance to cover, relative prey abundance, distance to trails, distance to human disturbance, and corridor width were important predictors of both wolf and cougar travel routes. I found that wolves prefer flat to gentle slopes in close proximity to forest cover (<25m), the latter being particularly important in corridors adjacent to high levels of human activity. Wolves preferred areas <50m from trails. Although wolves are sensitive to human disturbance, wolves utilized areas close to human disturbance (<500m) when other important characteristics were present including flat/gentle slopes and high prey abundance. I found that cover was a particularly important characteristic for cougars. They prefer moderate slopes, close to forest cover (<10m). Cougars also prefer areas <50m from trails and areas of moderate relative prey abundances. In order to optimize wolf and cougar use of wildlife corridors, land managers need to recognize that a combination of key habitat characteristics is required to maximize connectivity around developed areas

This study was unable to discern the true effects of human disturbance on wolves and cougars as they utilize corridors. For both species, responses to human disturbance were confounded by the mountain landscape, human dominance in valley bottoms and preference for other habitat characteristics. Results did suggest a differentiation between roads and high human use with an attraction to roads and an avoidance of high human use

(which includes residential, commercial and industrial areas). However, these results were spurious due to possible effects of multicollinearity (Tabachnick and Fidell 1996).

Recognizing trends in corridor use gives insight into the connectivity of the landscape and allows land managers to identify areas that may compromise connectivity. I examined both local-scale movement trends and population-level trends of large mammals use of corridors over 8 winters in BNP. I examined the efficacy of track transects to determine trends in corridor use. I found the use of track transects to monitor wildlife movements through corridors to be an effective technique for deer, sheep, coyote, wolf and cougar, but ineffective for elk. In areas that receive regular snowfall, track transects are an effective, unobtrusive, inexpensive method to monitor movement trends of most wildlife species.

I found overall decreasing trends of corridors use for deer, sheep and coyote suggesting that local populations of these mammals were declining, and increasing trends for cougar and wolf. Decreases in deer may be due to increases in predator (cougar and wolf) use of corridors and coyote decreases may be due to increased competition with wolves. Increases in predator use around the Banff townsite is likely due to increases in predator populations, as seen by the overall increasing trends across corridors. Local-scale trends, such as the wolf response on the Airfield and Vermillion transects, may also be attributed to recent management actions, including restorations and human use restrictions that have increased predator security in corridors. Local-scale decreases in use, as seen with deer responses on the Sulphur transect can be attributed to increased habitat loss from human development.

As human development and activities continue to fragment landscapes into isolated habitat patches, effective corridors will become increasingly important. Results from this research can be used by wildlife managers to monitor, maintain, restore, and design wildlife corridors to enhance connectivity for wolves and cougars and contribute to the long-term maintenance of these species in the Canadian Rocky Mountains.

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